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Environmental Analysis of the Chemical Release Module Program

James P. Heppner and Maurice Dubin

NOVEMBER 1980

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NASA Technical Paper 1750

Environmental Analysis of the Chemical Release Module Program

James P. Heppner and Maurice Dubin
Goddard Space Flight Center
Greenbelt, Maryland

NASA
National Aeronautics
and Space Administration

**Scientific and Technical
Information Branch**

1980

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PREFACE

The National Aeronautics and Space Administration has initiated a program for the development and operation of a Chemical Release Module Facility (CRMF) as part of the Solar Terrestrial Spacelab Program. The CRMF is an outgrowth of studies conducted by the Chemical Release Facility Definition Team (CRFDT) of the AMPS Scientific Working Group (AMPS-SWG). It is to function as a multi-user facility to perform chemical release experiments selected from proposals submitted by Principal Investigators (PI's) in response to a NASA "Announcement of Opportunity."

The Chemical Release Module (CRM) is an expendable free-flying spacecraft which is deployed from the space shuttle with an attached "kick motor" which is subsequently fired to place the CRM into the orbit required for the scientific objectives of the mission. The CRM is designed to carry a large number of chemical release canisters with provisions for carrying scientific instruments when they are needed for diagnostic functions. The canisters can be of various types and sizes in response to the specific scientific requirements of each experiment. This implies different chemical compositions, different release masses, and different modes of release ranging from nozzled thermite explosions of a solid mixture to the slow venting of a gas. The specific composition, mass, and location of each release will not be finally defined until experiments are selected. This introduces a potential uncertainty in environmental analyses in the sense that there is the possibility that experiments could be proposed that are not covered by existing analyses. Additional analyses may be required if or when this occurs. It is, however, unlikely that many such cases will arise in view of both historical precedents and the CRFDT's preliminary surveys of potential experiments which did not reveal experiments with a recognizable potential for having adverse environmental effects.

Historically, chemical releases have been conducted for scientific studies from several hundred sounding rockets over the past 25 years. Similar releases have been conducted from several orbiting vehicles at large distances from the earth and in one case at an altitude of 960 km over polar regions. To our knowledge these experiments have not produced an adverse public reaction in the sense of concern over environmental effects. Similarly, the scientific community has not been concerned with environmental effects except for the alteration of the natural abundance of lithium at altitudes greater than 80 km and for this case it was, in general, found that the release experiments contributed to, rather than handicapped, the scientific studies that were effected.

The lack of adverse reaction to previous release experiments has been based on two factors: one technical and the other psychological, as follows. (1) Knowledgeable scientists have not found reasons to believe that the releases have adverse effects. (2) The non-technical public within viewing range, notified in advance, and aware that the phenomena are transient, distant, and from a small amount of material, has observed the releases with interest and not fear. In view of this history, it becomes logical to ask why it was desirable, or necessary, to undertake an environmental review and analysis of the CRM releases. One basic reason is that NASA's NHB8800, "Procedures for Implementing the National Environmental Policy Act (NEPA)," requires an environmental assessment for new spaceflight programs and an analysis is a logical first step. Aside from this formal

requirement the reasons, relative to the past, relate to the potential "scope" of the CRM releases. Technically this means greater masses of selected chemicals and thus the need for examining cumulative effects. The difference, however, appears primarily in the realm of psychological impact. A brilliant red trail visible across the entire continental U.S. is likely to generate considerable public response. Uninformed, or incorrectly informed, segments of the population may attribute subsequent storms, earthquakes, air pollution, disease, etc. to these strange happenings in the sky. They may find it difficult to believe that such an extensive display could come from only tens of kilograms of common chemicals. Their apprehensions and questions must be answered by knowledgeable people who in turn must have confidence that the possibilities for environmental impact have been studied and documented and found to be negligible.

This report documents studies conducted in advance of the formal "Environmental Assessment of the CRM Program" which is to be a separate NASA document. It is to serve as both documentation for statements contained in the environmental assessment and as an independent referenceable source of information. It is in two parts: (1) the report of a review by a panel of highly qualified scientists, and (2) a reprinting of the environmental analysis conducted by Pressman Enterprises under a NASA contractual arrangement with the Applied Physics Laboratory, Johns Hopkins University for support of the activities of the CRFDT. The task of the review panel was twofold: (a) to bring forth any new environmental considerations, and (b) to review a draft version of the report from Pressman Enterprises to note any important omissions or errors. In free discussion, the panel brainstormed many thoughts and questions in addition to the attention directed to the common types of releases. This process further strengthened the key conclusion that "no deleterious environmental effects of a widespread or long-lasting nature are anticipated from chemical releases in the upper atmosphere on the scale and of the type indicated for the CRM program."

James P. Heppner
Maurice Dubin

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PART I

REPORT ON MEETING OF NOVEMBER 30, 1979 OF A REVIEW PANEL ON THE ENVIRONMENTAL ASSESSMENT OF THE NASA CHEMICAL RELEASE MODULE (CRM) PROGRAM

Prepared by

Ernest Bauer
Institute for Defense Analyses
Chairman of the Review Panel

January 25, 1980

REPORT ON MEETING OF NOVEMBER 30, 1979 OF A REVIEW PANEL ON THE ENVIRONMENTAL ASSESSMENT OF THE NASA CHEMICAL RELEASE MODULE (CRM) PROGRAM

Prepared by Ernest Bauer
(Institute for Defense Analyses)
Chairman of the Review Panel

January 25, 1980

INTRODUCTION

The membership of the panel convened by J. Heppner (NASA/GSFC) is listed in Appendix A. Panel members had been sent copies of a draft report "Preliminary Assessment of the Chemical Release Module Program."[1] The panel was briefed by J. Heppner on the CRM program, and by J. Pressman on his draft report. After extensive discussion and expression of the views of all the panel members, a preliminary report of this meeting was prepared by the chairman and iterated to the panel members and to all other attendees at the November 30, 1979 meeting (see Appendix B). All comments received by January 16, 1980 have been incorporated in the present report.

The key conclusion, endorsed unanimously by all panel members, is as follows: *No deleterious environmental effects–of a widespread or long-lasting nature–are anticipated from chemical releases in the upper atmosphere on the scale and of the type indicated for the CRM program.*

Releases of a variety of chemical species in the upper atmosphere in quantities of 10 to 100 kg or even larger have been conducted several hundred times since the early 1950's, when rockets suitable for use as payload carriers became available to study a variety of atmospheric problems such as high-altitude winds and electromagnetic fields by this technique.

In any such experiment there is the following dichotomy: injections must be on a large enough scale for the effects to be observable and useful, and yet small enough not to cause or trigger major perturbations of the atmosphere. In none of the past releases is there any evidence for significant, long-lasting, deleterious, environmental effects; the presently contemplated individual releases of up to 10 to 100 kg are not larger than past individual releases. Thus the present review panel endorses the conclusions of earlier assessments, such as that of a Committee on Space Research (COSPAR) group (see Kellogg, 1965), of the Space Shuttle[2,3] in anticipating that no long-term, large-scale, harmful environmental impact on the upper atmosphere or the biosphere would result from chemical releases in the upper atmosphere on the scale contemplated by the CRM program.

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[1] Pressman, J., "Preliminary Environmental Assessment of the Chemical Release Module Program," draft, October 1979.
[2] NASA, "Final Environmental Impact Statement for the Space Shuttle," April 1978.
[3] Ibid.

The present discussion addresses only the effects of deliberate chemical releases from CRM on the upper atmosphere or on people on the ground. It does not consider launch operations, including the effects of rocket effluents or the result of possible accidents, or operational factors such as the contamination of one spacecraft by a release from another spacecraft, or critical communication interference effects; all of these can be avoided by proper sequencing and design of operations.

OVERALL SCALE OF EFFECTS

While specific plans for individual experiments using the CRM have not yet been made, the cumulative annual rate of atmospheric releases from the CRM is estimated at less than 2000 kg per year according to studies by the Chemical Release Module Facility Definition Team, including perhaps 1000 kg of barium and 100 kg of lithium. Additional materials that may be injected include other alkali and alkaline earth metals, TMA (= $(CH_3)_3Al$), SF_6, NO, CS_2, and the combustion products of the release reactants. The input into the upper atmosphere of meteoroidal material has been estimated as (1.6-6) $\times 10^7$ kg per year (see Cosby and Lyle, 1965; Barker and Anders, 1968; Hughes, 1975). Thus, the total annual rate of mass injection is of order 10^{-4} times the total meteoroidal rate of mass injection; for particular species, however, such as Ba or Li this factor can be much greater, even exceeding unity.

SPECIFIC MATERIALS

Barium:

Metal and its soluble compounds are poisonous[4]; however, much or most of the atmospheric input will reach the lower atmosphere and ground as barium sulfate ($BaSO_4$) which is highly insoluble, chemically inert, and nontoxic. A simple, semiquantitative discussion given as Appendix C demonstrates that the contribution of CRM sources to the existing barium in the biosphere (lowest atmosphere and upper ocean) is very small (of order 10^{-6} or smaller).

Lithium:

One would expect a detectable enhancement upper atmospheric lithium as a result of contemplated CRM injections[5] but there is no known hazard resulting from this.

Other Injectants:

We did not consider other injectants in detail because, to our knowledge, no harmful effect has been suggested.

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[4]Part II of this volume, Appendix F.

[5]Part II of this volume, Appendix E.

Energy of Injection:

The energy of a release is the heat of reaction of the injectant, perhaps 100 kcal/mole or 4 eV/bond, plus the kinetic energy due to orbital motion with a velocity of approximately 7 km/sec. For a 50 kg release this is of order 2×10^9 joules. By comparison, an International Brightness Classification (IBC) Class I aurora (the weakest identified class), with a duration of 30 minutes and an extent of 10^6 km^2 corresponds to an energy deposition in the upper atmosphere of order 10^{13} joules; the energy deposition due to a chemical release is thousands of times smaller.

POSSIBLE ENVIRONMENTAL EFFECTS

Upper atmospheric visual glows resulting from Li, Ba, Sr, Na, etc. releases may be readily visible to the general public. They are transient (duration of some minutes) and produce no long-term or harmful effects.

Effects on Human Health due to Toxic Materials

See Appendix C for an estimate of the perturbation due to barium. In view of both the small relative injection as well as the insolubility of at least part of the material ($BaSO_4$), there is no data that would indicate a hazard.

Effects on the Ionosphere

Under certain conditions high-latitude chemical releases appear to have triggered small geomagnetic substorms (W. W. Berning, private communication). It is thus possible that, under conditions of full-scale, high-latitude CRM operation, up to 10 percent of small geomagnetic substorms may occur somewhat earlier than in the absence of chemical releases. (The principal effect of such a substorm is possible interference with ionospheric HF radio communication.)

The release of barium or other materials in the F-region produces local enhancement in ionization, which could change HF radio propagation characteristics. However, the scale of these perturbations lies within the natural variability in the ionosphere, and it is unlikely that natural and artificial perturbations to HF propagation can be separately identified.

Effects on Weather and Climate

It appears that at least some metals (Na, Mg) may reduce stratospheric ozone by a catalytic cycle (see Ferguson, 1978). However, the quantitative effect of metals from CRM injections is unlikely to be significant.

There are controversial suggestions of solar activity–climate interactions through the triggering of auroras or substorms (i.e. geomagnetic activity). Insofar as releases may perhaps trigger substorms (see p. 4) there might perhaps be some interaction. However, we do not consider this level of perturbation to be of significant impact.

Effects on Ground-Based Optical Astronomical Observations

This can probably be addressed during the operations by informing the relevant astronomical community when and where a release is to be made. The appropriate method of informing astronomers is the International Astronomical Union (IAU) announcement system, and there should be ample time to avoid adverse effects on observing programs.

Regarding long-term enhancement of the concentration of some trace metals such as lithium in the upper atmosphere, we know of no harmful effects from the case of lithium, even though lithium releases can be used to obtain knowledge about the dispersion of atmospheric gases around the Earth.

Satellite Operations

The effects of sputtering of surfaces on spacecraft and possible interference with critical radio communication links should be addressed in an operational context (see Introduction).

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APPENDIX A

PANEL MEMBERS

Dr. Ernest Bauer (Chairman)
Institute for Defense Analyses
400 Army-Navy Drive
Arlington, VA 22202

Mr. Warren W. Berning
(New Mexico State University)
11007 Candlelight Lane
Potomac, MD 20854

Dr. Herbert C. Carlson
Code ATM
National Science Foundation
Washington, DC 20550

Dr. Dan Golomb
RD-682
Office of Research and Development
Environment Protection Agency
Washington, DC 20460

Prof. Curtis L. Hemenway
Dept. of Physics & Astronomy
University of Maine
Orono, ME 04473

Dr. William W. Kellogg
National Center for Atmospheric
Research
Boulder, CO 80303

Mr. Herman E. Lagow
9336 Harvey Road
Silver Spring, MD 20910

Dr. John E. Naugle
7211 Rollingwood Drive
Chevy Chase, MD 20015

Dr. George C. Reid
Aeronomy Laboratory
NOAA
Boulder, CO 80303

Dr. S. F. Singer
Professor of Environmental Sciences
University of Virgina
Charlottesville, VA 22903

Dr. Fred L. Whipple
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, MA 02138

Prof. Edward C. Zipf
Department of Physics
University of Pittsburgh
Pittsburgh, PA 15261

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APPENDIX B

OTHER PARTICIPANTS IN THE MEETING OF NOVEMBER 30, 1979

Mr. Roland H. Chase
Code ST-5
NASA Headquarters
Washington, DC 20546

Mr. Nathaniel B. Cohen
Code LB-4
NASA Headquarters
Washington, DC 20546

Dr. Maurice Dubin
Code 963
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Dr. James P. Heppner
Code 696
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Dr. George P. Newton
Code ST-5
NASA Headquarters
Washington, DC 20546

Mr. Jerome Pressman
4 Fessenden Way
Lexington, MA 02173

Dr. David Reasoner
Code ES-53
NASA Marshall Space Flight Center
Huntsville, AL 35812

Mr. Leo Richards
Code JA-51
NASA Marshall Space Flight Center
Huntsville, AL 35812

Dr. Erwin R. Schmerling
Code ST-5
NASA Headquarters
Washington, DC 20546

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APPENDIX C

ENHANCEMENT OF AMBIENT BARIUM DUE TO CRM RELEASES

Let us assume a maximum plausible CRM input into the upper atmosphere of 1000 kg Ba per year. This is larger than the presumed meteoritic input of 3×10^{-6} (Mason, 1971) times $(1.6\text{-}6) \times 10^{7}$ kg per year (see Section 2), or 50-200 kg Ba per year.

Of concern to the biosphere would be the resultant enhancement in the atmosphere's planetary boundary layer (and spread uniformly over a depth of 1 km in the globe, this would give an enhancement of 2×10^{-7} $\mu g/m^3$-year) or in the upper ocean (spread uniformly over a depth of 50 m in the global ocean, this would give an enhancement of 6×10^{-17} gm/gm seawater-year, or 6×10^{-5} $\mu g/m^3$-year).

A mean turnover time in the atmospheric boundary layer is 1-10 days (see, e.g. Reiter and Bauer, 1975) and in the upper ocean, 100 to 1000 years (Broecker, 1963). Thus, with measured air values of .006 $\mu g/m^3$ in the atmosphere and 10^{-5} gm/gm seawater (see Part II, Appendix F, also Goldberg 1963, for references and ranges), fractional enhancements of barium are of order 3×10^{-7} in the atmosphere, or 2×10^{-9} in the ocean. These values may fluctuate by 1 to 2 orders of magnitude; note however, that some of the added material in the atmosphere will tend to be $BaSO_4$ which is insoluble, inert, and non-toxic.

Evidently most of the barium in the biosphere must be due to terrestrial sources such as wind-blown dust, sea spray, and the combustion of coal and other fossil fuels.

PART II

ENVIRONMENTAL ANALYSIS OF THE CHEMICAL RELEASE MODULE

Prepared by
Jerome Pressman

Pressman Enterprises
Lexington, Massachusetts
under Contract No. 601069

February 1980

ENVIRONMENTAL ANALYSIS OF THE CHEMICAL RELEASE MODULE PROGRAM

Prepared by Jerome Pressman
(Pressman Enterprises
Lexington, Massachusetts
under Contract No. 601069)

February 1980

SUMMARY

This is an environmental analysis for the Chemical Release Module (CRM) program of NASA. The findings indicate no adverse environmental effect on the basis of (a) the data from hundreds of previous chemical releases, (b) specific experimental analyses, (c) order-of-magnitude chemical release energetics and mass considerations, (d) comparison with other anthropogenic effects, (e) comparison with natural phenomenology and variability and (f) the input from other related environmental assessments. Consequently, it is recommended that no environmental impact statement be required.

The CRM program proposes to create a multi-user facility, Space Shuttle launched, which interchangeably accommodates a large number of chemical canisters for a variety of alternate chemical release experiments during the timeframe 1982 to 1986. These limited and controlled releases into the upper atmosphere, ionosphere, and magnetosphere have a capability for contributing toward the solution of key problems (for the earth and other planets) in atmospheric/magnetospheric coupling, space plasma physics, atmospheric dynamics and chemistry, gas dynamics, auroral phenomena, ionospheric communication disturbance, solar wind magnetosphere interactions, physics of comets, and more.

Moreover, the ability to move ahead on projected economic utilizations of space involving large-scale operations such as those inherent to the Solar Power Station (SPS) and the creation of large space structures is, in part, dependent on knowledge of the environmental effects of releases in space. The CRM releases can provide the types of information necessary for understanding the relevant interaction mechanisms and their effects. These studies will be a valuable by-product of the CRM science experiments.

The findings are that adverse effects are not expected because of the small masses involved and the transient nature of the environmental changes induced by the chemical releases No health effects are anticipated because the relatively small chemical release masses, diffused globally before reaching the earth's surface, are greatly diluted and their concentrations are many orders of magnitude below even the most ingent toxic standards. No effects on orbiting spacecraft are anticipated because the only phase of the release possibly affecting the spacecraft is during the expansion of the release when the particulate, neutral and ion densities are still high. Proper launch scheduling and coordinated trajectories can be utilized to eliminate this category. No detrimental effect on communications is expected because of the localized disturbance, the brief duration, the self-healing nature of the ionosphere, and, for most cases, the general isolated location of the disturbances.

Other than a short term and operationally insignificant change in lithium in the upper atmosphere, no significant compositional changes are expected. Because of the small masses and low energies involved, no changes in the magnetosphere are anticipated. No significant effect on astronomical "seeing" is anticipated because the limited luminous clouds created low in the atmosphere are generally short in duration while the deeper space clouds are of limited angular size and diffuse rapidly as they traverse the sky. Coordination with the astronomical community is recommended. Finally, no significant effect on weather or climate is anticipated since no significant changes in upper atmsophere composition or processes are expected.

If the CRM program proceeds as proposed and according to plan, there should be no significant impacts on the physical, biological, or socioeconomic environment as described above. Cost-benefit considerations indicate the high advantage of the program not only in terms of the scientific data to be obtained but also in terms of small scale pilot tests of the massive releases involved in projected space engineering projects.

There is an exceedingly small probability that a spacecraft with instruments susceptible to surface contamination could pass close to the CRM at the time of a release. To eliminate this possibility for contamination, it is recommended that follow-up technical analyses be directed toward defining "safe-distance" criteria and establishing operational procedures which can be implemented to prohibit releases at these rare times.

1. DESCRIPTION OF PROPOSED ACTION, OBJECTIVES AND BACKGROUND*

This report represents, for administrative purposes, an environmental analysis of the proposed Chemical Release Module (CRM) program and is being carried out in accordance with NASA guidelines, NMI 8800 7D, September 5, 1979 and Council on Environmental Quality guidelines, 43 FR 55978 (1978).

1.1 Description of Proposed Chemical Release Module (CRM) Program

1.1.1 General

The CRM program proposes the extension of known techniques for releasing chemicals in space from rockets to the Space Shuttle System and is described in detail in 1.3 in Appendix of Sources. More extended information on the CRM program is also given here in Appendix A, to which the reader is referred. This includes information on: Program Category, Planned Launch Times, Mission Lifetime, Mission Functions, Mission Elements, Typical Mission Orbits, Status, Approach Conceptual Mission Sequence, CRM Characteristics, Observing Operations and Program Schedule. The scientific objectives are given below in summary fashion and discussed in more detail in Source 1.3.

Development of a space transportation system based on a reusable Space Shuttle was initiated by NASA in early 1972. Initial program plans call for orbital flight testing in 1979 and operational status during 1980. Early operations at low inclination orbits are from the Kennedy Space Center (KSC) followed by activation of facilities at Vandenberg Air Force Base (VAFB) after 1983 to permit higher inclination orbital missions.

For twenty years, chemical release experiments carried by high-altitude sounding rockets have provided important data on the near-earth environment at relatively low cost. See Sources 1.5 to 1.39 for a partial list of references to this literature. Also see Appendix B for a brief discussion of chemical release history and background, a partial log of some chemical releases, and a brief discussion of the initial expansion phase of releases. The potential for chemical releases from the Space Shuttle has been identified by science advisory committees contributing to Shuttle experiment planning Source 1.3. Such experiments represent a substantial extension of rocket experiments because the availability of Space Shuttle transportation permits exploration of new areas in the ionosphere/magnetosphere and the capability to carry heavier weight. Additional benefits that accrue include the large range of altitudes and latitudes that may be covered, the orbital velocity incremental to the release velocity, the precision in release location, and the utilization of the Space Shuttle itself as an observation platform in space. The program also appears to be applicable to the concept of cost sharing with multiexperiment flights.

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*Liberal use has been made throughout this report of general descriptive material from various sources which are, in some cases, not completely referenced.

1.1.2 Technology for Chemical Release Systems

The technology of chemical release systems has been well developed over two decades of experimentation and is described in detail in Source (1.40) and in a series of Thiokol reports, (Sources 1.41 and 1.42). To create the desired effects, the selected chemical must be ejected in the proper state, usually as a gas or vapor, sometimes as a liquid for subsequent vaporization, and sometimes as solid particles. Liquids and gases are released by standard techniques while chemical reactions and explosion devices may provide vaporization energy for materials such as alkali metals. Dispensing mechanism and rates are varied depending upon the configuration required for the experiment–a long, thin trail, spherical cloud or high-velocity jet. Given in Table 1-1 is a list of chemicals utilized in previous high-altitude experiments. Figures B-1 and B-2 (Appendix B) show the launch locations and approximate altitude distribution for previous releases.

1.1.3 Initial CRM Mission Scenarios

As a preliminary environmental assessment, this document is directed specifically toward an initial sample listing of prospective CRM experiments and generically similar ones of a comparable mass class and not to all conceivable chemical release experiments.

Table 1-2 gives a sample listing of CRM experiments including identification code and experimental objectives, while Table 1-3 furnishes the mass, altitude and payload of the experiment. It is noted that most experiments are in the 5 to 100 kg class with a few designed for a 1000 kg mass.

Because of the large number of prospective experiments, scientific and operational details for the sample list are not furnished here but are available in the document of model mission profiles (Source 1.4). Therein can be examined the individual experiment scientific objectives, experimental scenario, release characteristics, etc., as described by a number of potential experimenters who provided inputs to the NASA CRM Facility Definition Team (CRM-FDT). This document Source 1.4 complements the more general description of the CRM program (Source 1-3) by including a wide variety of experiment concepts.

The structure of the magnetosphere and the diverse locations within the magnetosphere of the many chemical release experiments are illustrated in Figure 1-1. As necessary, further details will be furnished in the text. Table 1-4 provides a categorization of types of releases and the application of specific chemical releases to scientific objectives which are described in Table 1-5 and in section 1-2.

Table 1-1
Typical Chemicals Used in High-Altitude Experiments

Ba	Sr	C_2H_2
Na	Al $(CH_3)_3$	NH_3
Li	Al $(C_2H_5)_3$	B_2H_6
Cs	SF_6	B $(C_2H_5)_3$
Eu	NO	Fe $(CO)_5$
K	NO_2	Pb $(C_2H_5)_4$
Ca	CS_2	Kerosene
Al	CO_2	Misc. Explosives

Table 1-2
Initial List of CRM Experiments

Experiment Identification	Experiment Name
BH-1	Light Ion Transport and Acceleration
BH-2	Composition Anomalies
BP-1	Ionospheric Depletion Experiment
DT-1	Exploration of the Double Layer
DT-2	Magnetic Field Line Tracing
DT-3	Auroral Modification Experiment on Pulsating Aurora
ED-1	Wind Generation
ED-2	Auroral Modifications
ED-3,4,5,6,7	Conductivity Modification
ED-8	Cold Plasma Seeding
HG-1	Critical Velocity Experiment
HG-2	Creation of an Ionospheric "Bubble"
HG-3	Small Scale Structure of the External Plasma Flow
HG-4	Artificial Comet
HG-5	Tracing Primary Auroral Processes
KM-1,2,3,4	Planetary Electrodynamics
KP-1	Critical Velocity Experiment
L,A&D-1,2,3	Photochemistry and Chemical Reaction Rates
LL-1	Conductivity Modification
LL-2	Ionospheric Enhancement
LL-3	Ionospheric Depletion
LL-4	Wind Generation
L&R-1	Chemical Release on the L=4 Siple-Roberval Field Line
MD-1	Comparison of Auroral Zone Electric Fields
MD-2	Plasma Motions in the Magnetospheric Cleft Region
MJ-1	Ionospheric Depletion
MM-1	Active Ionospheric Modification
MR-1,2,3	Outer Magnetosphere Particle Tracing Studies
PF-1	Large Atmospheric Perturbations
RB-1	Atmospheric Dynamics
SE-1,2,3	Low Altitude Satellite Studies of Localized Chemical Releases
SR-1	Lidar Explorations of Chemical Releases
TG-1	Generation of Acoustic-Gravity Waves
VR-1,2	Conductivity Modification
WJ-1	Determination of the Electrodynamics of the Harang Discontinuity
WJ-2	Electric Field Configuration During a PC-5 Magnetic Pulsation Event

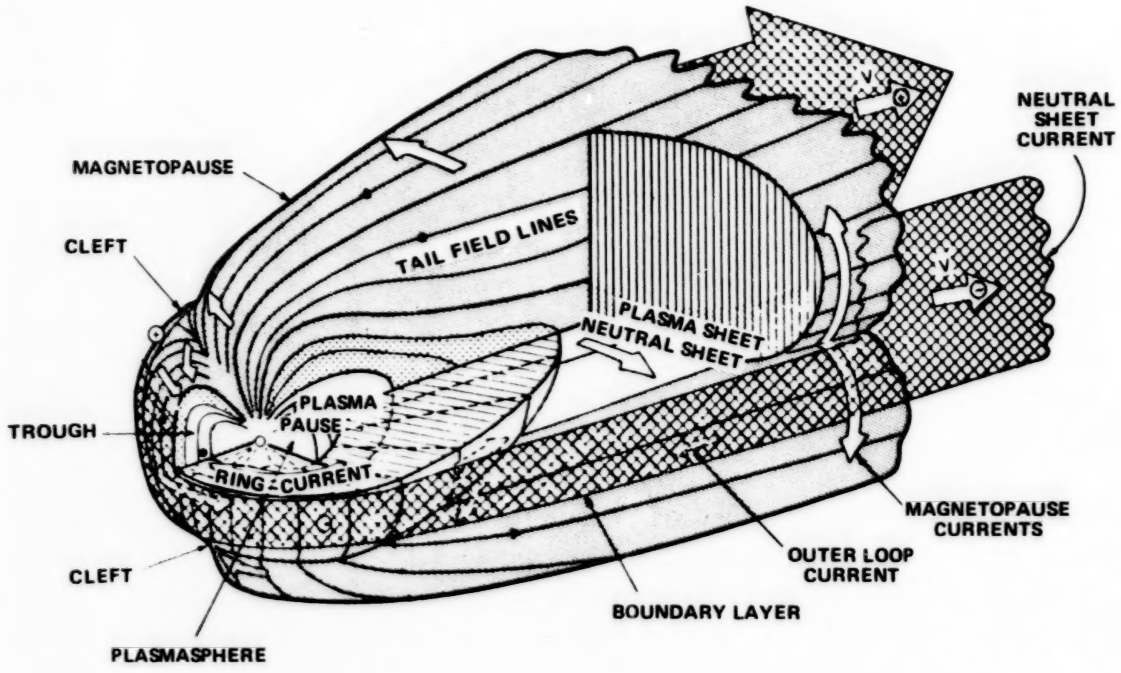
Source: Goddard Space Flight Center, "Developmental and Analysis of Model Mission Profiles for Chemical Release Experiments to be Conducted with the Space Shuttle Chemical Release Module Facility," September 30, 1980 in "Chemical Release Module Multi-User Facility for Shuttle Spacelab," Appendix.

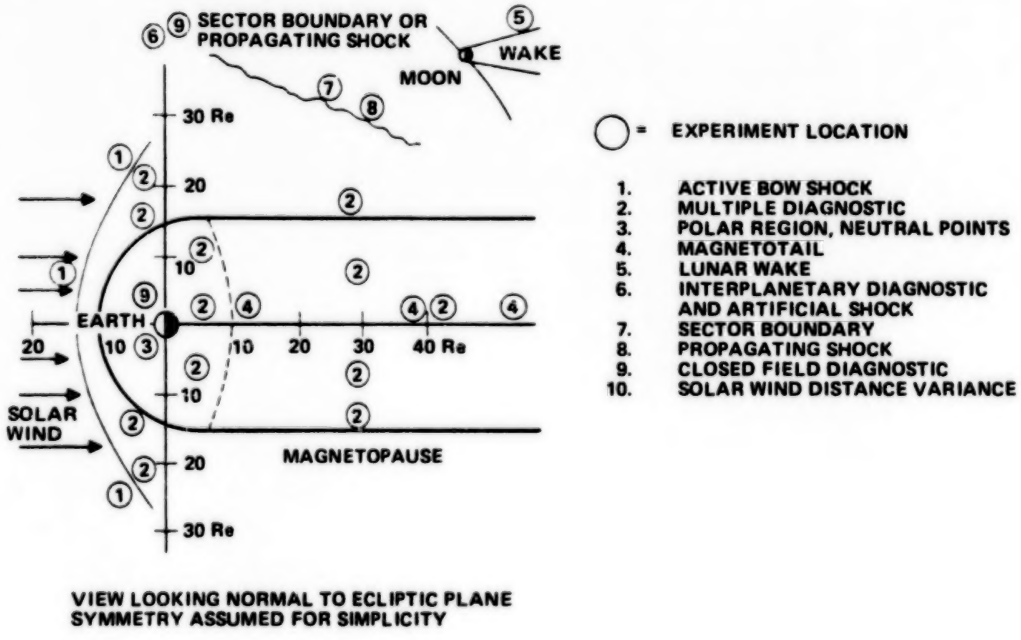
Table 1-3
Payload and Altitude for Initial CRM Experiments

Experiment Identification	Payload	Altitude (km)
BH-1	Thermite-Lithium - 70 KG	350
BH-2	Thermite-Lithium - 70 KG	180
BP-1	NH_3, H_2O, CO_2 - 100 to 200 KG	3000-400
DT-1	Barium Shaped Charge - Five Each total 2 KG of BA	400
DT-2	Barium Shaped Charge - One Each 2 KG of BA	400
DT-3	Thermite Barium - 10 KG	250
ED-1	Xenon or Argon - 4 Canisters 100 KG Each	130
ED-2	Barium Thermite - 1,000 KG	7,000
ED-3,4,5,6,7	1) BA, CS, or LI-Thermite; 2) CS; 3) AR,XE; 4) SF_6 5) WF_6, CS 100 KG	110-160
ED-8	CS or LI Vaporization, No Set Weight	23,000-40,000
HG-1	Strontium Shaped Charge - Two with 2 KG of SR	350-400
HG-2	Barium Thermite - Two with 10 KG Each	220-250
HG-3	Barium or Europium Thermite - 10 Canisters with 10 KG Each	8-12 R_E *
HG-4	Barium Thermite - 1,000 KG	20 R_E *
HG-5	Barium Thermite - 10 Each 16 KG	5,000-8,000
KM-1,2,3,4	Lithium, Barium, TMA - Series of Three 10-20 KG Each	250-300
KP-1	Xenon-10 KG	400-1,000
L,A&D-1,2,3	NH_3, CO_2, CH_4, H_2O, NO, NO_2, CO, FREONS - 20 Releases 10 KG Each	120-400
LL-1	Barium Thermite - 25 Canisters 16 KG Each	150-200
LL-2	Cesium and Tungsten Hexafluoride - 30 Each 30 KG	130-140
LL-3	Sf_6 Gas - 2,500 Canisters 1 KG Each	105-115
LL-4	XE, AR, or WF_6 - 64 Canisters 16 KG Each	150-200
L&R-1	BA or CS - 100 KG	3 R_E
MD-1	Barium Thermite - 10 Each 20 KG	150-250
MD-2	Barium Thermite - 10 Each 20 KG	300-400
MJ-1	Hydrogen - 100 KG	350
MM-1	Hydrogen - 100 KG	300
MR-1,2,3	Lithium, Barium, Cesium - 100 KG Each	4-20 R_E *
PF-1	Cesium Vapor - 1,000 KG	120-400
RB-1	TMA - 6 KG	140-200
SE-1,2,3	BA, NH_3, H_2, H_2O - 10 to 1,000 KG	150-800
SR-1	Barium or Sodium - 16 KG	180-450
TG-1	Thermite with Small Amount of BA or SR Doping	150-400
VR-1,2	Barium-Thermite, H_2, or H_2O - 100 KG Each	100-200
WJ-1	Barium-Thermite - 10 Each 16 KG	240-400
WJ-2	Barium-Thermite - 10 Each 20 KG	350

*R_E = Earth Radii

Source: For scientific objectives and experiment scenarios see, Goddard Space Flight Center, "Chemical Release Module–Multi-User Facility for Shuttle Spacelab," Appendix, September 30, 1980.





Source: Thiokol, "Chemical Releases from Space Shuttle Payloads," Wasatch Division, Ogden, Utah, May 1975.

Figure 1-1. Possible Chemical Release Experiments

Table 1-4
Application of Chemical Release Experiments to Scientific Objectives

Chemical Designation			1. Chemical Tracer							2. Modification and Perturbation							3. Plasma and Chemistry					
			a	b	c	d	e	f	g	a	b	c	d	e	f	g	a	b	c	d	e	f
Thermite Devices		Al		X					X											X		
		Ba	X	X	X	X		X	X	X		X	X	X		X	X			X	X	X
		Cs								X		X	X	X		X	X				X	X
		Eu			X							X	X			X				X		X
		Li		X	X	X	X		X			X	X			X				X		X
		Na		X					X											X		
		Sr		X					X											X	X	
Liquid/Gaseous Systems		Ar								X	X				X			X	X			
		CO_2								X	X			X	X		X	X	X			
		DB		X					X											X		
		He																X	X			
		NO							X									X	X			
		O_2						X		X	X				X			X	X			
		SF_6								X	X			X	X							
		SiF_4								X	X				X							
		TMA		X					X											X		
		WF_6								X	X				X							
Explosive Devices	Shaped Charges	Ba	X	X	X	X			X			X	X			X	X					X
		Eu			X							X	X			X						X
		Li			X	X	X		X			X	X			X						X
	Grenades	Al		X					X											X		
		Ba	X	X	X	X			X	X		X	X	X		X	X			X	X	X
		Cs								X		X	X	X		X	X				X	X
		Eu			X							X	X			X				X		X
		HEX													X							
		Li		X	X	X	X					X	X			X				X		X
		Na		X																X		

Source: Thiokol, "Chemical Releases from Space Shuttle Payloads," Wasatch Division, Ogden, Utah, May 1975, p. 2-7.

Table 1-5
Scientific Objectives of CRM Experiments (1 of 3)

1. Objectives of Tracer Chemical Releases in the Ambient Environment

   a. Provide comprehensive global measurements of the electric field ($E_\perp$) for general application to magnetospheric/ionospheric physics and to support investigations requiring the time history of the electric field over regions of space.

   b. Make neutral wind measurements in a synoptic and comprehensive manner for defining existing characteristics, dynamics, and possible coupling with ionospheric phenomena.

   c. Determine the geometry and distortions of the magnetic field lines between the high latitude ionosphere and the equatorial plane of the magnetosphere or regions near the magnetophase to improve the ability to relate phenomena in the distant magnetosphere to phenomena observed at ionospheric altitudes.

   d. Map magnetic field lines between conjugate points to confirm or modify field models and to ascertain conditions under which equipotential conditions are not existent along the field.

   e. Follow particle access into the magnetosphere and the transport and energization processes within the magnetosphere to answer questions on the location and efficiency of solar plasma transmission into the magnetosphere, to map large scale convection patterns within the magnetosphere, to map large scale convection patterns within the magnetosphere, and to estimate, quantitatively, energization and loss processes for particle populations in the earth's radiation belts.

   f. Locate the source of energetic magnetospheric ions to determine whether they may be of ionospheric origin.

   g. Complete measurements of atmospheric density, diffusion coefficients, temperature and concentration of certain species at high altitude.

Source: Thiokol, "Chemical Releases from Space Shuttle Payloads," Wasatch Division, Ogden, Utah, May 1975.

Table 1-5
Scientific Objectives of CRM Experiments (2 of 3)

2. Chemical Releases Modification and Perturbation of Natural Systems

   a. Alter ionospheric conductivities locally by increasing ionization, decreasing ionization, or inducing gross movement of the neutral atmosphere to observe the reaction of the magnetosphere/ionosphere system and determine the nature of its circuit/generator characteristics and perhaps simulate a magnetic substorm.

   b. Trigger instabilities to determine the controlling boundary conditions, to study their temporal and spatial development, and to relate their effects to previous ground based observations.

   c. Create a magnetospheric whistler duct of known enhanced plasma density, extent, and location to increase understanding of plasmospheric dynamics and the interaction of whistlers and ducts.

   d. Investigate image effects of conductivity changes in the lower ionosphere to locate the field conjugate points in the two hemispheres.

   e. Generate atmospheric gravity waves to provide basic data on the nature and characteristics of gravity waves and their relation to traveling ionospheric disturbances.

   f. Study wave simulation by introduction of particles to obtain basic information on wave-particle interactions.

Table 1-5
Scientific Objectives of CRM Experiments (3 of 3)

3. Chemical Releases for Plasma and Chemical Technology Experiments

   a. Simulate cometary materials and plasma to observe their interaction with magnetic and electric fields.

   b. Simulate planetary atmospheres to study molecules and radicals found around other planets.

   c. Obtain basic data on reaction rates and test atmospheric chemistry hypothesis in support of attempts to develop a unified model of the atmosphere.

   d. Determine atomic and molecular properties of certain metals that cannot be observed in the laboratory such as radiation and oxidation processes involving metastable states as well as transisition probabilities, photoionization cross sections, and chemical reactivity of ground state and excited atoms.

   e. Study the interaction of a neutral gas and ambient plasma with critical relative velocities to investigate the ionization coupling observed in laboratories.

   f. Observe moving and stationary plasma interactions with the atmosphere and ionosphere-magnetosphere to provide basic data on plasma processes.

1.2 Objectives

The CRM program has for its primary function scientific objectives. It is designed to facilitate the use of chemical releases as a scientific tool in the further understanding of our upper atmosphere/ionosphere/magnetosphere environment: by tracing, modifying and simulating natural phenomena and testing theories in these regions. Relevance also extends to applied problems such as in simulating conditions which adversely affect space communications and space operations.

1.2.1 Scientific Knowledge (See Source 1.3 for more extended discussion)

The CRM program is relevant to answering key questions of (a) solar plasma entry into the magnetosphere, (b) solar wind vs. ionosphere as source of magnetospheric plasma, (c) processes injecting ionosphereic ions into the magnetosphere, (d) causes of high latitude electric fields and aurora, and relation to substorms, (e) energy mechanisms in the thermosphere and (f) solar/weather correlations. Some of the major objectives for chemical release experiments are listed in Table 1-5 which demonstrate the high degree of relevance and versatility of the CRM system in responding to key outstanding questions regarding the structure and behavior of the earth's space environment.

Such CRM experiments can also play an important role in elucidating the magnetosphere of other planets in the solar system; Jupiter, Venus, Mars, Moon, etc., and elsewhere in the universe.

1.2.2 Engineering Applications of Knowledge Gained

The necessity to solve earth-bound problems (e.g. the power shortage) and the inherent advantages of many space operations (e.g. satellite communications) have initiated large-scale multiple use of the upper atmosphere/ionosphere/magnetosphere space environment. These domains have become literally a "common" for many operational and planned systems. As the CRM experiments yield data, they, as described in Subsection 1.3.1, can further clarify many of the scientific problems (see Table 1-5). In this manner, limited and controlled CRM experiments can have input into the engineering design and architecture of massive space systems such as the planned Solar Power Systems (SPS) which involves the deposition of millions of kilograms in the 2 to 6 earth radii plasmaspheric region.

The full exploitation of space must rest upon exact knowledge of how the engineering operations alter space, interact with other space systems, and contaminate themselves and their environment and thus modify their functional effectiveness. The architectural design of such systems must include as a basic design element the cited three interactions (Source 1.43).

Table 1-6 summarizes some of the expected input and applications of CRM data in elucidating space and communications system interactions with the environment. The many inputs indicate a high degree of relevance, particularly for such massive systems as the SPS. For many space operations there are needs for models of the low-energy, near-earth plasma as indicated in Table 1-7 from Garrett (Source 1.44) which identifies the "user" community and its needs. The CRM can serve the useful function of validating such models.

Table 1-6
Applications of CRM Data to Elucidating Space and Communication Systems Environmental Interactions

A. Analysis of Effects of Environment on Communications and Space Systems

1. Communications Systems

   a. CRM data applicable to natural ionospheric variations
   b. CRM data applicable to transionospheric transmission variations
   c. CRM data applicable to magnetic effects

2. Space Systems (These include Space Power System (SPS), Space Laboratory, Space Colony, Geosynchronous Orbit Operations–communications, meteorology, etc.)

   a. spacecraft charging interactions
   b. sputtering and chemical interactions
   c. power transmission effects
   d. optical limitations and effects
   e. space ion beam storage system

B. Analysis of Effects of Space-Systems on Environment, Other Space Systems and Self

1. Environmental Modification

   a. modification of ionosphere by large vehicles
   b. contamination of plasmasphere by LEO to GEO transfer
   c. upper atmosphere composition change by HLLV (Heavy Launch Lift Vehicle)
   d. magnetospheric modifications by gas release from large space structure
   e. other

2. Effects on Other Space Systems

   a. effect of SPS build-up on GEO communications satellites, etc.
   b. effect of space colony on other space systems
   c. other bilateral interactions

3. Self-Contamination Problem for Each Space System

Table 1-7
Applications of CRM Data to Validate Near-Earth Plasma Models -
Users of 0-100 KEV Near Earth Plasma Models

User	Needs
1. DOD/NASA Commercial	A. Cumulative Flux Dosages
	B. Mission Planning
	C. Satellite Design/Operation
	D. National Defense
2. NOAA Air Force Air Weather Service	A. Mission Failure Analysis
	B. Forecasting
3. DOE/NASA	A. Environmental Impact Assessment
4. Scientific Community	A. Reference Models
	B. Ionospheric Models
	C. Substorm Modeling
	D. Plasma Dynamics
	E. Solar/Terrestrial Coupling

Source: Garrett, H.B., "Review of Quantitative Models of the 0-100 KeV Near-Earth Plasma," *Reviews of Geophysics and Space Physics,* vol. 17 no. 3 (May 3, 1979).

1.3 Geophysical Background

Material of a general geophysical background to assist the non-expert and explicating the technical terminology is placed for the most part in Appendix C. This Appendix contains (a) basic geophysical data, (b) a brief discussion of the ionosphere, and (c) some data on micrometeorites.

1.4 Related Environmental Assessments (EA) and Impact Statements

Selected related environmental assessments and impact statements having direct and indirect input into the subject CRM assessment are described briefly and summarized below. Environmental assessment by the Los Alamos Group (Source 1.45), the DNA (Defense Nuclear Agency) group (Source 1.46), the AFGL group (Source 1.47), and the NASA/Wallops Group (Source 1.48) have been performed for their specific chemical release programs and no environmental impact has been found. The first two were barium release programs and bear directly on the CRM program as does that of the AFGL group which used a variety of chemicals. The Los Alamos group Operation BUARO EA involving a 9.1 kg shaped-charge barium release at 500 km found no deleterious effect. The DNA Stress program EA involving five 48 kg barium releases at 183 km at Eglin Field, Florida found no harmful environmental effects. The DNA ICECAP program at the Poker Flats Range, Fairbanks, Alaska, involved a series of barium releases at 180 to 200 km for a total of 417 kg of barium during a 2-month period with one release (a cluster of canisters) amounting to 128 kg. No deleterious environmental effects were found. The AFGL program involved the release at Eglin Field of a broad range of chemicals (see Table 1-1) at altitudes of 150 to 200 km; this amounted to 100 kg per year. No measurable adverse effect on man and his environment was found. The Wallops Environmental Assessment involved the release of 13 kg of barium at five earth radii above lower latitudes. The Space Science Board of the National Academy of Science found no environmental impact.

A correlative environmental assessment, that of the Space Shuttle itself, "The Environmental Impact Statement, Space Shuttle Program Final, April, 1978" (Source 1.49), regarding upper atmospheric effects due to exhaust effluents found "significant decrease in the F_2 layer (see Appendix C) will occur and may last for many hours." It concluded "air glow effects would be minor" but that "radio wave propagation effects may include inability to perform radio astronomical measurements at low frequencies, enhanced radio scintillations and changes in the efficiency of radio communications at low frequencies. These effects will be localized along the orbital track and will not persist for more than a day after the OMS (Orbital Maneuvering System) burn." It further found "no significant effect on communications or radio propagation." It is noted that the decrease of the F_2 layer by the OMS of the Space Shuttle will be an order of magnitude greater (or equivalent) than any proposed CRM electron depletion experiments.

An earlier study by Kellogg (Source 1.50) found no detrimental pollution of the atmosphere by rockets.

An important on-going study "Preliminary Environmental Assessment for the Satellite Power System" (Source 1.51) has and will have additional inputs for the CRM assessment program in the area of effluent effect on the ionosphere and magnetosphere. This truly massive program, which proposes to place in orbit each year two 35 000 to 50 000 ton satellites would deposit annually 140 000 tons of hydrogen, 800 000 tons of oxygen, 25 000 tons of argon and 15 megatons of high-energy explosive energy equivalent or 6×10^{16} joules of energy. The CRM program itself has a potentially strong input into the SPS program and chemical releases are being considered for the extended SPS assessment program.

The related environmental assessments, both past and on-going, described above, have been included as a matter of completeness and technical requirements. Upon the basis of data available, there have been no detrimental environmental effects for any of these previous chemical release programs when they were subsequently performed.

2. EVALUATION OF POTENTIAL ENVIRONMENTAL IMPACT (INCLUDES EFFECT OF NEUTRAL AND IONIZED MOLECULES AND PARTICULATES)

This section, together with the relevant technical appendixes, constitutes the major portion of the environmental analysis. Section 2.1 is concerned with the nature of assessment considerations and the line of argument in performing the present assessment analysis, while the remainder of this section is concerned with summarizing the technical evaluation. The details, for the most part, are relegated to the technical appendixes.

2.1 Analysis of Assessment Strategies

Outlined in this section is the general assessment approach and logic. To assist the overall assessment and to serve as a major line of evaluation, a tabulation of energetics, mass, and time scales is included.

2.1.1 Logic of Assessment and Assessment Criteria

While the scientific analysis of the details of any individual chemical release experiment may be complex, the overall environmental analysis may be straightforward, e.g. (a) the quantity of chemicals added may be insignificant compared to the natural meteoric influx, (b) the energy of the release may be minuscule compared to natural processes, (c) identical or highly analogous experiments may have been performed before with no environmental effect, etc.

In Table 2-1, there is furnished a list of generalized criteria for the assessment of chemical release experiment environmental effects which will act as a guide to assessments. The criteria, which overlap to some extent, move in a rough ranking order from direct comparison with a previous more-or-less identical experiment to that of a more-or-less theoretical analysis without closely related experimental data. In Figure 2-1 a schematic of the analysis of the CRM environmental assessment is presented.

2.1.2 Tabulation of Energetics, Mass and Scales

Presented in this subsection, in tabular form, are some scales of geophysical and other phenomena which can serve to delimit the environmental effects of the CRM experiments and put them in appropriate perspective. More extensive geophysical data is located in Appendix C. In Table 2-2, the energy of chemical release is compared to geophysical and other phenomena. On the scale of geophysical phenomena, substorms, total earth magnetic energy, etc., the energy of the projected releases is, in general, quite small. In Table 2-3, the tonnage of ambient atmospheric gases around the earth in shells ten kilometers thick for an assumed molecular weight of 16 is presented for chemical release comparisons. These numbers can be compared with the release of 0.5 tons from a typical CRM mission.

Table 2-1
Considerations Involved in Assessment of Chemical Release Experiments: Individual or Class Environmental Effects

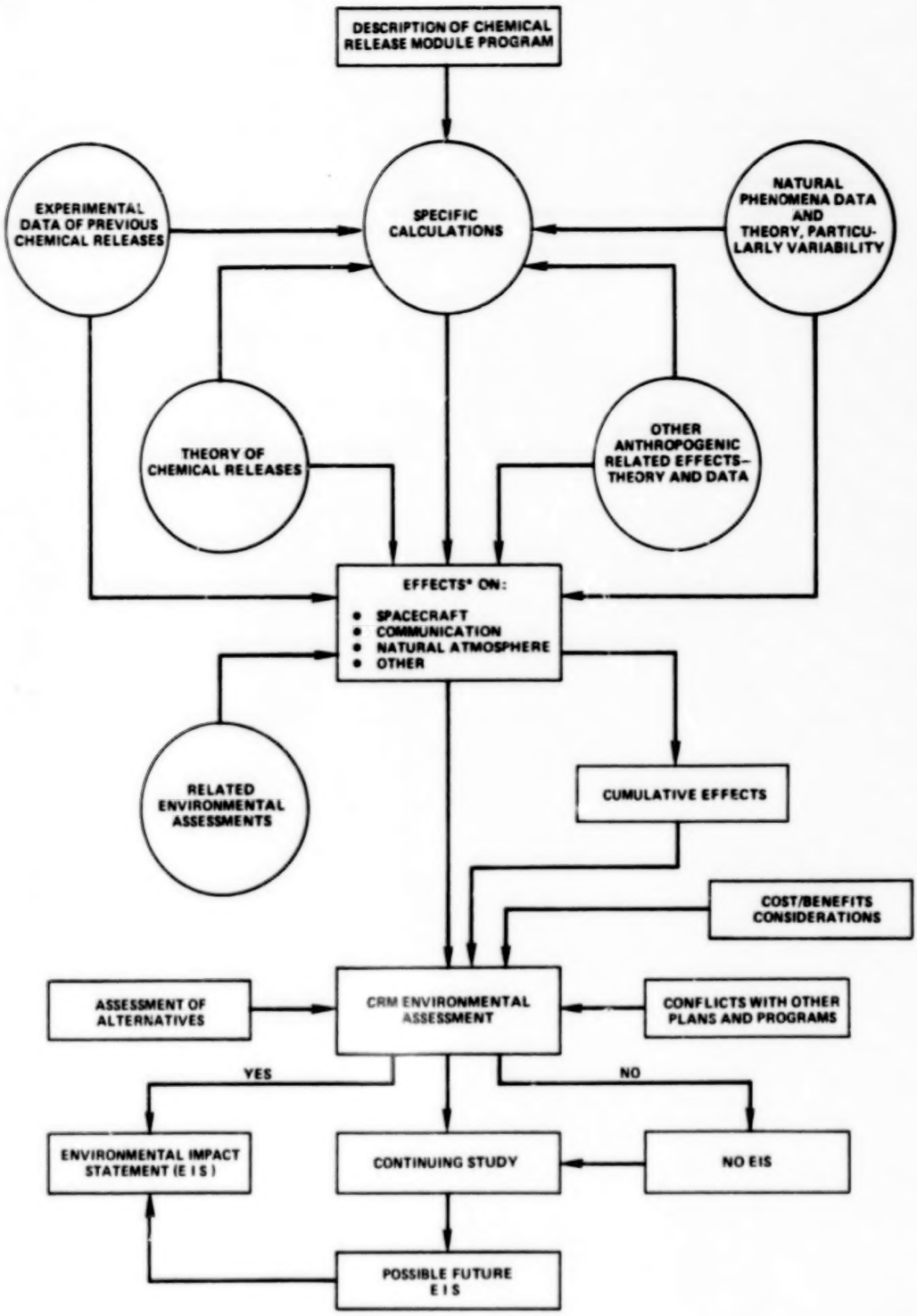
1. Comparison to Experimental Data and/or Theory of Identical or Closely Similar Chemical Release Experiments

2. Specific Calculation Based Upon Well Founded Theory and Comparable Experimental Data

3. Mass and/or Energetics (or other) Comparison to Similar or Related Natural Phenomena and/or Processess (Time and Space Scales) thereby Setting Limits

4. Mass and/or Energetics Comparison to Related Anthropogenic Phenomena and/or Processes (Time and Space Scales)

5. Considerations Based Upon Theory for the Most Part with Little Data



*Includes neutral, ion and particulates

Figure 2-1. Schematic of Analysis of Chemical Release Module (CRM) Environmental Assessment

Table 2-2
Comparison of Chemical Release Energetics to that of Various Geophysical and Other Phenomena and/or Processes

Phenomena or Process	Energy or Power	Comments
A. Energetics of Chemical Releases		
1. Non-moving mass converted to high explosive equivalent		
1 kg	4.2×10^6 joules	Approximately 4×10^{-12} of auroral energy on February 11, 1958
100 kg	4.2×10^8 joules	4.2×10^{-4} of geomagnetic storm input to thermosphere for 1 to 2 seconds, or approximately 10^{-10} of total auroral energy on February 11, 1958.
2. Kinetic energy for orbital velocity of 8 km/sec		
1 kg	3.2×10^7 joules	
100 kg	3.2×10^9 joules	
B. Some Geophysical Phenomena/ Processes		
1. Very strong earthquake	$10^{11} - 10^{12}$ watts	
2. Total solar power at top of atmosphere	1.8×10^{17} watts	
3. Total UV solar power at top of atmosphere	10^{12} watts absorbed above 100 km	
	4×10^{11} watts absorbed above 120 km	

Table 2-2 (continued)

Phenomena or Process	Energy or Power	Comments
4. Energy of earth's dipole, magnetic field above earth's surface	9×10^{17} joules	
5. Power of solar wind over earth's cross section	10^{13} watts	Electric power consumption of U.S. X 10
6. Magnetospheric input to thermosphere through auroral process	5×10^{10} to 10^{11} watts	
During geomagnetic storms	5×10^{11} to 10^{12} watts	
7. Bright aurora of February 11, 1958	10^{14} watts for several hours or 10^{18} joules total energy	An extremely strong aurora
8. IBC class I aurora	For duration of 30 minutes and area of 10^6 km^2 corresponds to energy deposition of 10^{13} joules	Weakest identified class of aurora
C. Some Man Made Processes		
1. Total electric power consumption of U.S.	10^{12} watts	
2. Large power plants (gigawatts)	10^9 watts	
3. HLLV rocket exhaust	9×10^{10} watts	HLLV - Heavy Launch Lift Vehicle projected for the solar power satellite (SPS)

Table 2-3
Tonnage of Material in a Shell Around the Earth, Ten Kilometers Thick, for Various Concentrations

n (particle/cm^3)	H (km)	ρ (H) (gm/cm^3)	M_T (tons)
10^5	1,100	2.5×10^{-18}	2.5
10^6	900	$\times 10^{-17}$	2.5×10^1
10^7	700	$\times 10^{-16}$	2.5×10^2
10^8	500	$\times 10^{-15}$	2.5×10^3
10^9	350	$\times 10^{-14}$	2.5×10^4
10^{10}	250	$\times 10^{-13}$	2.5×10^5
10^{11}	150	$\times 10^{-12}$	2.5×10^6

H is the approximate height of the particle concentration n as found in the atmosphere, ρ(H) is the density at this altitude, and M_T is the tonnage of this number of particles of molecular weight 16 contained in a shell 10 km thick around the earth.

2.2 Effects on Orbiting Spacecraft and Their Instruments

2.2.1 Direct Consideration

Any effect on orbiting spacecraft and their instruments due to the CRM program is not considered significant because of the low probability that any operational spacecraft in the vast expanse of space would pass through the chemical release cloud while its density (particulates, neutral or ionized) is high enough to impinge detrimentally on the spacecraft nor is it expected that the orbital environment would be modified significantly. It would be extremely unlikely that another spacecraft would have exactly the same or only slightly different orbital parameters as the CRM and, thus, follow closely the orbital motion of the chemical release cloud. Hence, at most, a single traverse through the chemical release cloud is possible during its initial, most dense phase since the cloud and spacecraft will separate on divergent orbits.

The discussion below illustrates the insignificance of contamination at a distance of 50 km for a typical release. There is, however, a finite probability that a second spacecraft with ultra-sensitive instrumentation could pass much closer to the CRM and, in such cases, there could be a risk if a release was activated near the time of minimum separation. The risk is completely avoided if releases are not conducted at these rare critical times. Accordingly, there will be a need to establish operational criteria that prohibit the occurrence of a release at such times. Inasmuch as these criteria will depend on detailed consideration of separation geometries, instrument susceptibilities, and errors associated with orbit predicts, their formulation, and the modes of implementation become the functional responsibility of the NASA, which must apply similar considerations to the firing of upper stage rocket motors. Thus, criteria applicable to orbit intercepts are not considered in the present analysis.

As an example of the probabilities and numbers involved, presented in Appendix D (source 2.1) are calculations of the effects of ar[illegible]tal release of 32 kg of a barium mixture at 900 km impinging on a spaceship at a distance of [illegible] immediately after an explosion. These calculations appertain to the advance planning conditions for the Cameo experiment which was successfully performed in October 1979, and had no deleterious effect on other spacecraft including the Nimbus-G spacecraft which was ejected from the same launch vehicle and thus followed a similar orbit.

The overall conclusion for this specific calculation is that the particle contamination level in orbit will be less than levels present in factory-to-launchpad environments under the most highly controlled handling procedures. The predicted level in orbit, in fact, represents a negligible change relative to accepted micrometeorite levels. The analysis indicates that the particle density at 50 km will be at least four orders of magnitude less than the class 10 000 cleanroom and that the individual release particles will have 10^{-5} to 10^{-6} the energy of micrometeorites of the same mass for the co-orbital case in which the equivalent micro-meteorite exposure is hours to days. For a counter-rotating satellite, the situation is different since here the relative velocity can be approximately 14 to 16 km/sec and the equivalent micro-meteorite exposure is approximately 85 to 285 days. Finally, there are an insufficient number of gaseous molecules at 50 km separation distance (or at equivalent expansion radius) to form a monolayer (only 10^{-5} coverage) on spacecraft surfaces even assuming that all particles contacting the surface adhere to the surface. While a simple isotropic

expansion model has been used, more careful orbital considerations in Appendix D support these results.

The level of deposition which is acceptable is determined primarily by the criticality of the spacecraft surface finishes and the types of experiments flown. Highly critical optical devices would be adversely affected by thicknesses as low as 0.005 micron while solar cells would probably not be degraded by thicknesses up to 0.05 micron; if adequate solar cell surface is provided, even greater thicknesses could be tolerated in localized regions.

Consequently for a 50 km and greater "separation" distance, the effect on the spacecraft and spacecraft sensors are not significant for the payload considered. Different size payloads may be scaled accordingly. It is considered that by locating the point of release with an appropriate "separation" distance operational satellites will be adequately removed from the "expansion" phase of the chemical release and suffer no detrimental effects from released particles or neutral gas molecules.

With regard to the effect of charged particles for thermal barium (Ba) releases, the maximum integrated "column" content of Ba^+ near release points is of the order of 10^{11} ions/cm^2 for most releases from individual canisters. Many satellites fly across the auroral belts four times each orbit. Typical ambient field aligned currents associated with average aurora are 10^{-8} to 10^{-10} amperes/cm^2. This means 10^{-8} to 10^{-10} coulombs/cm^2 sec or 0.6×10^{11} to 0.6×10^9 charged particles/cm^2. Thus, the satellite would have to "suck up" nearly all the Ba^+ ions contained in the magnetic flux tubes intersecting its orbit to reach ambient conditions. There is no mechanism for doing this. The most that could happen is that the Ba^+ might reduce the normal negative charge of a few volts (or less) by a small fraction of a volt for several seconds at the release point if the satellite was very close to the release point. Where shaped-charge barium releases are ejected up a magnetic field line, the probabilities of an operational satellite flying along this line and close to the release point are exceedingly small and again are susceptible to timing and scheduling of the release.

As a corollary since there are no significant effects expected for orbiting spacecraft during the chemical release expansion phase, because there is a continuous spreading of the particles along the orbit (See Appendix D), subsequent orbital particle effects on spacecraft are even less significant. Similar remarks appertain to the neutral molecules which undergo further dilution due to diffusion as do the ions which also recombine. Due to infrequent and spatially different CRM injections, no significant buildup in orbit occurs.

2.3 Effects of Chemical Releases on Communications and Comparison with Other Effects

2.3.1 Chemical Release Effects on Communications

It is considered that any significant environmental impact of the CRM program on an operational communications system is extremely unlikely. This is because of the localized disturbance that is created (tens of kilometers to, at most, several hundred kilometers in size), to the brief duration of the disturbance (minutes to hours) resulting from its self-healing nature, and to the general location of the releases which are, for the most part, planned for equatorial, polar-auroral, and oceanic areas. Moreover, only a small number of ionospheric modification experiments a year are presently likely

from the planning schedules. In general, specifically designed experiments with specialized equipment have been necessary in the past to make requisite experimental electromagnetic measurements. The lack of environmental effect is evidenced by the fact that of the approximately 350 chemical releases to date involving space and atmospheric perturbations, there have been none or insignificant perturbations to commercial and other operational systems on the basis of available evidence.

Moreover, as pointed out below, there are many natural perturbations to communications such as auroral particle precipitation, ionospheric irregularities (Spread-F), scintillations, geomagnetic storms, etc., of larger magnitude but comparable nature (see Subsection 2.3.2). (In fact, some chemical releases are designed to simulate some of these natural phenomena.) Consequently, the chemical release perturbation on a spatio-temporal basis constitutes, at most, if at all, a potentially small fraction of this total array of natural communication disturbances.

There have also been other types of man-made disturbances of the ionosphere of a comparable or much larger size. The ionospheric heater program (Source 2.2) in which high-intensity radio waves energized the ionosphere at locations in the continental United States (Platteville, Colorado and Arecibo, Puerto Rico) has also produced ionospheric changes greater than or comparable to those anticipated in the CRM program. Additionally, these changes have been observed to be rapidly reversible and not to have had significant effects on regular communications.

The significant reduction and rapid return of the Total Electron Content (TEC) of the ionosphere by the introduction of H_2O/H_2 molecules in the F-region by the Skylab event on May 15, 1973, (Source 2.3) indicates the strong self-healing properties of the ionosphere even under massive chemical releases hundreds of times greater than projected by CRM scenarios. Moreover, a lack of disruptions in operational communications systems was evidenced by the absence of any significant outages. This was probably, for the most part, because of location of the trail over water indicating the effect of geographical locations distant from active communications circuits in minimizing disruptions.

At present, there exist reasonably well-developed theories of electron enhancement due to the release of ionizing material (Source 2.4) and of electron diminution due to depleting material (Sources 2.5 and 2.6) in the ionosphere so that the overall characteristics of the types of electron enriching and depleting releases are reasonably well established both by observation and theory. Additional theory has been developed for release from orbit (Sources 2.7 and 2.8). In general, because of the rapid spread of material higher up in the ionosphere, releases planned beyond 300 km (F-region) will have a less significant communications effect since the electron density changes will be smaller and more transient and dispersed more rapidly.

Communications disturbances evoked by releases creating changes in momentum and hence winds and waves are also evaluated as causing short-term and insignificant communications perturbations in the ionosphere at best comparable to natural fluctuations created during the onset of magnetic storms. The effect of much greater momentum releases due to missile exhausts have created no substantial communications alterations. A chemical release in the equatorial ionosphere to simulate natural ionospheric perturbations (Spread-F) at most will create one more instance of a natural scintillation phenomenon, the so-called electron-depletion bubble (Source 2.9).

Moreover, the relatively insignificant communications perturbations of the CRM program are many orders of magnitude less than those of the projected large-scale space engineering programs (Solar Power Stations, etc.) for which it can provide important environmental data.

2.3.2 Comparison to Normal Ionospheric Fluctuations

To provide a further perspective on the CRM-induced ionospheric effects, a brief summary of natural ionospheric short-term fluctuations, some of which have been mentioned in Subsection 2.3.1, is presented here. The main point is that the ionosphere is not a static but rather a dynamic system with diurnal, seasonal, and solar cycle variations and with many intermittent phenomena which present a varied picture to electromagnetic propagation. Moveover, the proposed CRM experiments present a non-operationally important and small fraction relative to these natural fluctuations.

A summary of the normal ionosphere with the elements of radio propagation is presented in Appendix C, while a more extended description is available in Source 2.10. It is observed that irregularities in ion concentration occur everywhere on the globe, nearly always at high latitudes, often at night at low latitudes and not often at mid-latitudes. The scale size of variations ranges from hundreds of kilometers to tens of centimeters with the degrees of variation increasing with scale size. For example, variations in concentrations as large as a factor of 10^2 to 10^3 can occur often near the equator (Spread-F) and give rise to fading in the gigahertz frequency range. A class of Traveling Ionospheric Disturbances (TID's) has been observed moving from high latitudes toward the equator presumably caused by auroral heating events. The polar ionospheric regions in general are subject to considerable perturbation with a whole sequence of effects beginning with Sudden Ionospheric Disturbances (SID's), an electromagnetic disturbance (ultraviolet and X-rays), followed by Polar Cap Absorption (PCA) from energetic protons entering the polar ionosphere to the slower ions and electrons that 20 to 40 hours later cause the magnetic and ionospheric storms and aurora. See Source 2.10 for a description of the varied ionospheric irregularities and Source 2.11 for a description of the many varied communications effects, outages, scintillations, anomalous reflections, etc.

2.4 Effects of Chemical Releases on Atmospheric Compositions

2.4.1 General Conclusions

It is concluded that there will be no significant detrimental chemical release effect of the CRM program on the natural abundance of trace constituents including particulates in the upper atmosphere/ionosphere/magnetosphere regions. The major argument here is that in the CRM experiments, there are, for most experiments, relatively small masses released (kilograms to at most hundred of kilograms per individual experiment) compared to the existing mass of the upper atmosphere as given in Table 2-3 and that even for the few 10^3 kg releases that might be feasible, the relatively rapid dissipation and spread of material in the expanse of outer space will prevent any substantial modification of the composition of the upper atmosphere/ionosphere/magnetosphere system. Direct comparison may also be made with the natural input which gives an approximately daily accretion of 50 to 150 tons (Source 2.12) of meteoritic material which is annually equivalent to 10^4 times the projected one-ton per annum of materials released in the CRM program.

The charged particles created in the releases as indicated in Section 2.3 are limited spatially and temporally and dissipate at most in hours. Also, past experiments have not produced any significant environmental effects. Further, the particulates (see Section 2.2) from any release are of limited mass, spread out rapidly, and except for a duration of minutes around the CRM, they have no significant effect on the particulate environment. Suitable logistics, timing, and planning adjustments can be made for the in-close orbit intercept problem. No significant detrimental effects, other than short-time, localized experimental perturbations are expected for the magnetosphere because of the limited mass and energies involved. See Table 2-2 for comparison of the energies, and Subsection 2.4.5 on the scope of the possible magnetic perturbations.

The information gaps identified are those of (a) perturbation of the lithium content in the upper atmosphere (see Appendix E) for a time scale which is not clearly defined but for which no adverse consequences are established and (b) lifetime of ions at low latitudes at distances of several earth radii. The first has no identified operational significance while the second may be substantially clarified by a chemical release experiment because of its scientific importance.

2.4.2 Changing the Natural Abundance of Trace Constituents Including Particulates

The probability of projected chemical releases changing the natural abundance of trace constituents in the environment on any basis except on a local and transient time scale is considered insignificant except for the concentration of lithium in the upper atmosphere in the altitude range 85 to 105 km. The alkali elements, barium and water vapor are perhaps the only elements of concern because of their relatively large percentage of use. Because of the extremely fast diffusion in the upper atmosphere and the relatively small CRM injection rate (e.g. $1\text{-}2 \times 10^{3}$ kg per year), no significant perturbation (except on a highly transient and local scale) can be anticipated, except for lithium. General calculations for water vapor and hydrogen indicate that the product of injection rate and characteristic residence time when ratioed to the ambient loading give very small, insignificant perturbation loadings regardless of the geophysical regime. It is considered that lithium, whose total mass in the upper atmosphere above 70 km amounts to less than a kilogram, is the only gas in the upper atmosphere that may be significantly perturbed for more than a few hours, perhaps of the order of days or weeks as analyzed in Appendix E. However, it is considered that there are no significant operational consequences for such a change and, moreover, such perturbations should prove useful to the study of natural lithium behavior.

The subsequent history of metal atoms and ions introduced above the atmosphere is still uncertain. As they diffuse down through the atmosphere, however, they probably undergo chemical reactions with atmospheric species that convert them into a variety of metallic compounds. They may be removed either through rainout in the troposphere or through incorporation into aerosol particles in the lower stratosphere. Some of the metallic species may react with stratospheric ozone, but the quantities involved in the CRM release experiments are so small by comparison with both the natural flux of metals of meteoric origin and effluents from combustion sources at the earth's surface that no significant effects are expected.

The case of barium deserves further considerations since it is a component of many of the chemical releases and demonstrates the small absolute and percentage changes that will occur. In the chemical

release experiments, elemental barium is introduced at a high altitude either by shock compression of a thin metallic shell or by chemical reaction. After convection under the influence of electric forces, the vaporized barium will gravitate toward the earth as very fine particules, oxidizing to BaO as it enters the denser atmosphere. Much of this may convert to the hydroxide and the carbonate as it disperses and proceeds downward in the presence of water vapor and carbon dioxide. Its small particle size should result in long residence times in the atmosphere (perhaps 5 to 10 years) as illustrated by strontium 90 fallout measurements.

Throughout the long residence lifetime, the barium will be widely dispersed by air currents and should mix well with the atmosphere. Complete mixing of 10^3 kg of vapor produced in a large experiment with a global volume one kilometer deep will result in incremental concentrations of about 2×10^{-7} $\mu g/m^3$. This concentration is less than 3×10^{-4} the measured air values (see Appendixes C and F).

2.4.3 Changing Densities of Species that Have a Key Role in Weather and Climate

No significant effects on weather and climate are anticipated. This is because no significant change in atmospheric composition will occur. Moreover, as of the present time no significant effects on weather and climate have been consensually identified with composition changes in the upper atmosphere above 100 km.

2.4.4 Introducing Chemicals Hazardous to Health

No significant effect on health is expected. This is primarily because of the small amounts of chemicals introduced at high altitudes are extremely diluted by the extensive mass of the atmosphere and broadly spread over the world during their long passage (years) into the troposphere and ground. As an example, a pessimistic estimate of the concentration in man's immediate environment may be found by assuming that the total yearly amount of all material released is concentrated in the lowest kilometer of the atmosphere and spread uniformly over the globe. Taking 1000 kg of material over this volume gives a concentration of 2×10^{-13} grams per cubic meter, some 1 million times below the threshold limit value concentration of the most toxic substances listed by the American Conference of Governmental Industrial Hygienists (see *The CRC Handbook of Laboratory Safety*, the Chemical Rubber Company, Cleveland, Ohio, 1971). Because of the use of barium in a high percentage of experiments, additional information on its chemical and toxic properties is furnished in Appendix F as a matter of general information.

2.4.5 Perturbing the Magnetospheric or Ionospheric Structure

It is considered that no significant or lasting perturbations will occur to the magnetospheric or ionospheric structure for the range of experiments being considered for the CRM program. This is based upon the low level of energy created in the chemical releases as displayed in Table 2-2 when compared to the natural energetics of the magnetosphere/ionosphere system and to other anthropogenic perturbations. The high-energy explosive equivalent of the largest chemical release presently being considered (1000 kg) amounts to less than 1 percent of a geomagnetic storm energy for one

second, approximately 10^{-9} of the total energy of February 11, 1958 aurora, or 10^{-8} of the energy of the earth's dipole magnetic field above the earth's surface (or other comparisons from Table 2-2). No significant magnetospheric or ionospheric perturbation is anticipated.

In somewhat more detail, the proposed chemical release experiments given in Table 1-5 can be classified as (a) tracer experiments, (b) perturbation and modification experiments, and (c) plasma and chemical technology experiments. The first and third categories of experiments, because of their nature and objectives, have been essentially environmentally assessed in the earlier sections of this report and in the preceding energy scale analysis of this section. While category (b), the perturbation and modification experiments, have been order-of-magnitude circumscribed by energy and mass considerations above, some further remarks are adduced below directed to the various types of such experiments.

Those experiments designed for mechanical modification making use of the Space Shuttle's 8 km orbital velocity are aimed at perturbing the atmosphere to artificially generate wind and wave motions in the upper atmosphere to test the dynamic effects on electrical properties and to study wave propagation. Atmospheric winds and waves are generally changing and omnipresent features of the upper atmosphere and such induced changes as may occur due to chemical releases represent one more relatively short term variation since the energies involved are relatively small. Upper atmospheric Traveling Ionospheric Disturbances (TID's) are, it is noted, a common feature of the upper atmosphere particularly under geomagnetic storm conditions (Ref. 2.13). Previous rocket ascents such as those of Apollos 15, 16, and 17 in the regions 30 to 150 km (Sources 2.14, 2.15) created wave phenomena detected at the ground having no detrimental environmental effect. Consequently, the mechanical modification type of experiments will have no detrimental effect.

Another class of modification, an electrical one, proposes changing the conductivity in auroral regions in order to observe the ionospheric/magnetospheric circuit response. The environmental changes affected here would involve transient changes in the intensity and form of the aurora which it is noted is a semi-permanent and highly fluctuating phenomena at high latitudes. Present theory (Source 2.16) considers that the aurora is an electrical discharge phenomenon which is powered by the solar wind-magnetosphere dynamo (see Figure C-4, Appendix C). The conductivity of the auroral zones has great variability because of the marked changes in the energetic ionization fluxes of the solar electromagnetic and corpuscular radiation (see Subsection 2.3.2). In particular, as a magnetic substorm develops, major changes in conductivity are caused by the auroral particle bombardments, lasting for 10 to 20 minutes to several hours, of 10^{11} to 10^{12} W. As a measure of change in conductivity, the brightness of auroras varies in intensity over a factor of 1000 from below the visual threshold to that which produces illumination on the ground equivalent to full moonlight. From another viewpoint, a barium release of 10^3 kg at 10 percent efficiency could produce 4×10^{24} ions, only enough to cause a 10 percent change in ion density over a 34 km cube or equivalent volume having an original 10^6 ions/cm^3. The change produced by the chemical release would represent one more fluctuation in a highly fluctuating and frequent phenomenon and conceivably might change the appearance of the aurora over a limited region.

Other proposals to seed with cold lithium the equatorial magnetosphere beyond the plasmasphere are designed to precipitate electrons and protons creating a localized and short-term patch of aurora, ionization, and atmospheric heating similar to the aurora itself and similar to the effects

achieved at the conjugate points by many shaped-charge barium experiments (Sources 1.33 to 1.39). A similar proposition involves seeding magnetic flux tubes closer to the earth with again the possibility of creating an analogous luminous phenomenon on a small spatio-temporal scale.

Another type of experiment proposes the creation of an electron depletion "bubble" at the magnetic equator. This is a "simulation" type experiment of "Spread-F" which produces scintillation effects and is a frequent phenomenon in equatorial regions. Hence, a short-term scintillation may occur– one of many naturally occurring such scintillations which occur on the average (depending upon the fading definition) 7 to 15 percent of the observing period in summer months for Kwajalein and 30 percent for Huancayo.

Finally, one proposed, maximum perturbation experiment involves using boiled off cesium atoms which are collisionally ionized in the atmosphere (120 to 400 km) by the orbital velocity, and subsequently impinge against magnetic field lines to study ionosphere/magnetosphere coupling. The kinetic energy of the cesium amounts to some 3×10^{10} joules prior to ionization and other energy losses involved in the collision process. Such energy assuming 100 percent effectiveness is approximately 3×10^{-4} of the energy for one second of the bright aurora of 1958. It can be anticipated to cause fluctuations (the purpose of the experiment) along the relevant field line. It is noted that the magnetosphere has proved stable to the above cited stronger shocks that accompany impulsive auroral events.

2.4.6 Changing the Astronomical Seeing Problem

No deleterious effect is anticipated that will significantly affect the astronomical "seeing" problem. The optical effects produced by the CRM program do not differ for the most part from those created by approximately 350 chemical releases (mostly of a radiating character) in the past two decades, and which have been performed, on the basis of the information available, without significantly affecting astronomical operations.

In Appendix G is given an evaluation of the effects on various branches of astronomy of changes in night sky brightness per se without inclusion of geometrical or time duration factors of the specific chemical release experiment. It is noted that all of the proposed luminous experiments create glows which are transient in nature, due to the limited mass involved and rapid spreading, lasting at most for tens of minutes, to possibly an hour or two. Also in Appendix G is a table of the brightness level of various natural phenomena and for mutual comparison, the various brightness levels for different transient chemical release features. There is described below, in order, the various types of luminescence involved in releases: (a) chemiluminescence, (b) resonance scattering, and (c) both point and trail releases at various heights.

The type of luminescence produced by one class of experiments utilizing chemical reaction with atmospheric components (chemiluminescence) is generally restricted to the lower ionosphere (under 250 km) and is restricted in scale (tens of kilometers) and time (tens of minutes). There is available for chemiluminescent clouds existing and reasonably adequate theory (Source 1.20). Because of the spatio-temporal factors and the geographical location of the release generally away from observatories, the deterrence to astronomical observations for this type of cloud is considered not significant as borne out by many such past experiments (Source 1.20).

The second class of a chemical release optical affect, that of resonance radiation created by solar resonance scattering generally from released atoms or ions such as neutral barium, barium ions, lithium, strontium, etc., has been extensively used in hundreds of experiments. Such releases, either point releases close in to the earth (500 to 600 km) or shaped charge ejection along magnetic field lines from high-latitude regions which have gone out to distances of 4 to 5 earth radii, glowed for periods of time up to an hour and have not constituted a significant deterrent to astronomy. Adequate theories of the expansion of orbital releases in collision and free expansion regimes are also currently available (see Appendix B). The recent successful Cameo release of barium in orbit at 900 km involving the release of 32 kg of barium mixture and 7.6 kg of lithium mixture has had no detrimental astronomical effect. An illustration of the geographical horizontal distribution of ions created by the orbital releases is furnished in Figures 2-2 and 2-3 which are Cameo pre-test calculations.

With regard to magnetospheric ion releases, those conducted along high-latitude magnetic lines opening to space have been shown to move directly out away from the earth (Source 2.17) and have had no perturbing effects. There remains a question as to the lifetime of ions and hence of their resonance luminescence in the equatorial region of the plasmasphere at distances less than 4 to 6 earth radii. This lifetime problem for equatorial releases constitutes an area to resolve. It would seem, perhaps paradoxically, that a limited and controlled chemical release here might be the optimum procedure for obtaining the desired answer.

Present judgment seems to be that the lifetime near four earth radii may be some 100 hours as caused by the average duration between large magnetic substorms (Source 1.43). At this particular distance and latitude the loss-cone angles are a few degrees. Moreover, barium ions are particularly stable since they do not charge transfer, become neutral, and move out freely from magnetic control.

With regard to the outer magnetosphere, the releases to be used in this regime (beyond 5 to 6 earth radii) are of the resonance type which emit only spectroscopic lines. The surface brightness of resonance clouds does not depend on the distance but the angular size does. Because of the rapid thermal expansion (approximately 1 km/sec) and the orbital velocity, it is considered that for reasonable masses, under 10^3 kg, a cloud brightness greater than 10 percent of the night sky for a limited field of view would not exceed a duration of several hours. As a sample calculation, for a 10^3 kg mixture, 3.8×10^{26} barium atoms are generated and at an isotropic dispersion (for a simplistic model) of 1 km/sec, a surface brightness of 10^8 photons/cm^2 sec or 0.1 kilorayleigh (10 percent of the night sky brightness) is reached in some four hours. The angular width at this time for a distance of 20 earth radii is approximately several degrees and the cloud under its original velocity and magnetic convection (depending upon its position) is undoubtedly also moving across the sky. It is considered that because of the short durations, spectral line nature, relatively small angular size, and angular traverse across the sky, that no significant deterrence to astronomical observations will occur for this and smaller releases.

The above isotropic expansion model is a gross one certainly, since once the ions have been created (e.g. approximately 20 seconds for Ba^+ and 200 seconds for Eu^+) the cloud is more cylindrical. The physics of the detailed interaction of an ionized cloud with the magnetosphere is exceedingly

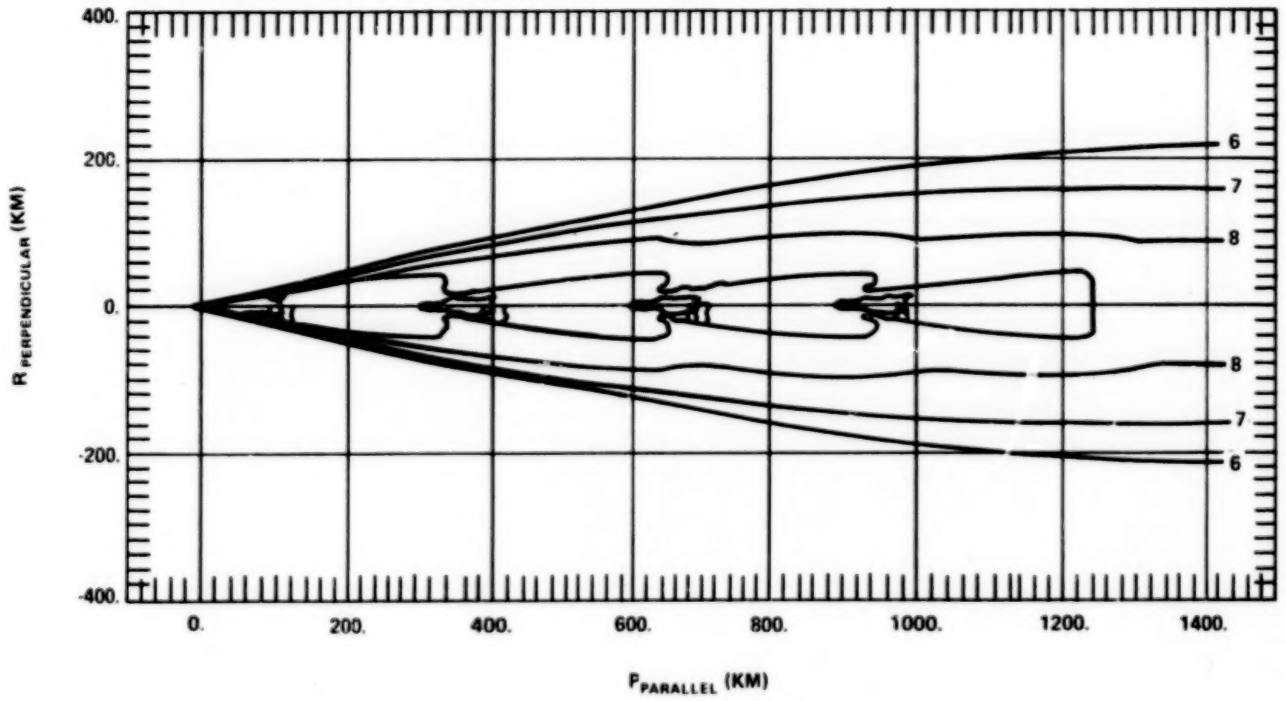


Figure 2-2. Column densities of Ba ions, (Units: 10^n particles/cm^2) (Cameo Information Memo)

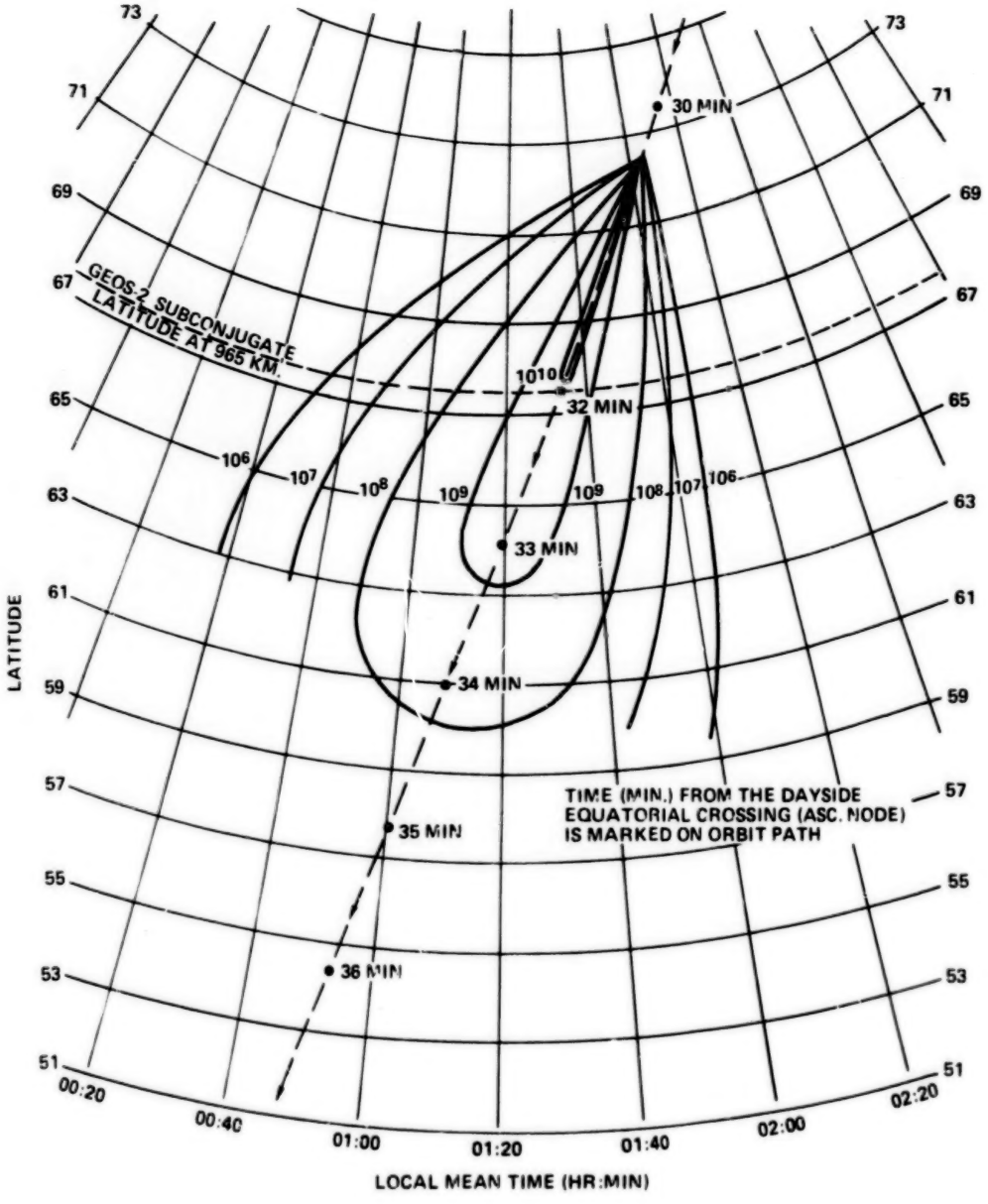


Figure 2-3. Cameo Orbit with Column Densities (P/cm^2) of Ionized Lithium (Li^+) 200 Sec., Pre-flight Estimates After Initiation of Release (Cameo Information Memo)

complex, involving striation formation and differential velocities parallel and perpendicular to the magnetic field, as elucidated by Scholer (Source 2.18), Pilipp (Source 2.19) and Haerendel and Lust (Source 2.20). The isotropic model is used to give an order of magnitude estimate only. For comparison purposes, in the HEOS experiment two moles of barium (1.2×10^{24} particles) were released at 12 R_e (Source 2.20). After some 25 minutes of observation by a Schmidt telescope, the cloud measured 2000 by 100 km. With surface brightness scaling as square root of mass, increasing the observed HEOS data by a factor of 17 for the 10^3 kg release would not put the estimated hours limit too far off, at least in terms of the Schmidt observation.

It is emphasized that, at most, a release would only interfere with observations from an observatory if they were examining that particular area of the sky at the particular time. (And only if the observatory had clear skies at that particular time for surface observatories.) The probability of interference per year would be the product of the above probabilities and the chance for even one case of interference becomes extremely small even for the most active observatories.

2.5 Summary of Environmental Effects by Chemical Releases in the CRM Program

The major findings of the analysis are summarized here as well as some gaps in our understanding. Recommendations for research thereto are given in Section 8.

2.5.1 Health Effects

No health effects are anticipated because the relatively small chemical release masses diffuse globally before reaching the earth's surface, are greatly diluted and their concentrations lie many orders of magnitudes below even the most stringent toxic standards.

2.5.2 Effects on Orbital Spacecraft

No effects on orbiting spacecraft are anticipated because the only phase of the release possibly affecting the spacecraft is during the expansion of the release when the particulate, neutral, and ion densities are still high. It is highly improbably that a second orbiting spacecraft will be located within a relatively small "separation distance" at a release time, where the "separation" is defined as a safe distance. Moreover, appropriate scheduling and timing of releases can be utilized as necessary to eliminate what is already a small probability. Because of the rapid diffusion of gases and ions, the spread of particulates, and the loss processes, no significant "orbital contamination" will occur for the limited mass and relatively infrequent CRM releases.

2.5.3 Effect on Communications

No significant effect on communications is expected because of localized disturbance that is created (tens of kilometers), the brief duration of the disturbance (minutes to hours) resulting from its self-healing nature, and the general location of the releases planned which are for the most part in equatorial, polar-auroral, and ocean areas. The movement of the disturbed area also mitigates the duration of any specific blockages should they possibly occur.

2.5.4 Effect on Trace Elements in the Upper Atmosphere

No significant effect on trace elements in the upper atmosphere is anticipated with the exception of lithium where a temporarily increased abundance may be observable in twilight for as long as several weeks. Such an increase has no known operational consequence and is valuable for understanding the natural lithium sources and sinks.

2.5.5 Effect on Magnetosphere

No significant effect on the magnetosphere is anticipated in terms of the relatively low energies and masses of the release vis-a-vis the enormous energies involved in the natural systems and their perturbations (e.g. geomagnetic storms).

2.5.6 Effects on "Astronomical Seeing"

No significant effects on astronomical seeing are anticipated. The chemiluminescent type of cloud is generally low in the atmosphere, limited in dimension and visible duration (tens of minutes) and can only locally and transiently effect astronomical observations. Resonance radiation clouds within the lower atmosphere and high-latitude magnetosphere generally have a duration of tens of minutes to several hours and may (e.g. in the case of lithium) cover larger areas. Because of the rapid fading of neutral clouds, the confined nature of ion clouds, the spectral line character of the radiation, and the movement across the sky, the potential interference with astronomical observations is either very brief and localized or occupies only a small area of the sky for at most several hours. Releases in the outer magnetosphere because of their limited mass, duration, angular size and traverse, will similarly not interfere with astronomical observations. Present relative uncertainties as to ion lifetime and confinement, and thus backgraound luminescence, in the plasmasphere at low latitudes do not greatly change the duration of "seeing" effects relative to other regions of space. Spreading along field lines and other dispersive effects limit the duration of optical detection to approximately one to two hours at the brightest location.

2.5.7 Effect on Weather

No significant effect on weather or climate will occur since no significant change in upper atmosphere composition or processes is expected. Moreover, there is as of this data no commonly agreed upon relationship between atmospheric composition changes above 100 km and the weather or climate.

3. CUMULATIVE AND LONG-TERM ENVIRONMENTAL EFFECTS

On the basis of the information available, it is believed that there will not be any significant cumulative and/or long-term effects from the types of chemical releases being considered for investigating the upper atmosphere-ionosphere-magnetosphere system.

4. ASSESSMENT OF ALTERNATIVE TO THE PROPOSED ACTIONS

The fact that chemical releases, as a technique, have been utilized as an investigative tool for approximately 20 years emphasizes their applicability in attacking new problems as they arise in space physics. The ability to trace, simulate and modify conditions and phenomena in space provides key information that cannot readily be attained by other means.

The need for the general purpose multi-user capability embodied in a chemical release module (CRM) system on the Space Shuttle is based on the need and demand from the scientific community, from the operational requirements and from the cost benefits that accrue. Specifically, the CRM is responsive to the large number of proposed experiments, to the mass requirements for large and small releases, to the need for flexible operational modes, and to the cost advantages of modular design and standardized system design and fabrication.

The CRM program also is unique in that it makes it possible to perform types of chemical release experiments which could not easily be implemented by other approaches. This includes among others the utilization of the shuttle high orbital velocity as a parameter in the experimental design.

Major alternatives to the CRM program include (1) not conducting the program and (2) conducting a less extensive program. Conducting the program at other locations is not possible since each experiment has unique location requirements. A number of other minor alternatives also exist, such as using different payload chemicals, deployment techniques, etc. Since the program has been designed to incorporate the engineering and economic factors which maximize the benefit-cost ratio and there appears to be no reason to alter the program for environmental reasons; such minor alternatives are not meaningful.

If the CRM program is not conducted, the objectives cannot be met. These objectives are deemed sufficiently important in both the scientific and applied space engineering areas to warrant the program being carried out. The magnitude and pacing of the CRM program has been planned to ensure that the major scientific objectives of the program will be met. A lesser number of releases would degrade the overall effectiveness of the program.

Consequently, on a cost-benefit basis and considered an integral part of the total scientific exploration and economic exploitation of space there are no viable alternatives to the proposed action.

5. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

The commitment of resources to the CRM programs at this stage involves the preparation of preliminary scientific and engineering, planning, design and organizational documents. At a more advanced stage, an adaptable module accommodating standard canisters of various sizes, specialized canisters and tanks, instrumentation submodule, ejection options, electronics, etc., will be fabricated. None of the materials utilized is scarce.

It is considered that the preliminary expenditure of human and material resources at this time is justified by the need for the proposed program.

6. KNOWN OR POTENTIAL CONFLICTS WITH STATE, REGIONAL, OR LOCAL PLANS OR PROGRAMS

On the basis of the information available, there has not been identified any known or potential conflict with any state, regional or local plans or programs.

7. ANTICIPATED BENEFITS VS. THE ENVIRONMENTAL COSTS OF THE PROPOSED ACTIONS

It is considered that the benefits accruing from the proposed actions will far outweigh any environmental effects. Such effects are not considered significant on the basis of information currently available. The benefits which accrue are very considerable ones in solving key outstanding questions of the large-scale behavior of our upper atmosphere/ionosphere/magnetosphere environment and plasma behavior. The expansion of information due to this CRM program is also applicable to our exploration of the magnetosphere of other planets. Moreover, the data obtained also has a high degree of applicability to such applied areas as communications, and the general economic utilization of space and military needs.

With regard to the economic utilization, there are magnetospheric and ionospheric impacts involved in large-scale space transportation with chemical and ion engines and in the operation of large-scale space structures. The overall design of such massive systems as the Solar Power System, military systems and even possible space colonies must take into account not only their impact on the environment but also their mutual interaction. The CRM program, as one of limited and controlled material releases in space, has direct input into their environmental assessment. Military needs are reflected in the opportunities for improved understanding of atmospheric optical sensing systems and communication perturbations, etc., as well as the environmental assessment of military systems themselves. The limited and controlled CRM releases serve as a valuable prelude to the massive releases projected for large-scale space engineering systems.

The environmental costs of the CRM are regarded as not significant. Some chemicals, e.g. barium, will be introduced into the upper atmosphere in minuscule amounts having no health consequences. Perturbations to civilian communications are unlikely and at worst brief and transient. With appropriate scheduling and spacing, no effects on other spacecraft or any other space system are foreseen.

8. RECOMMENDATIONS ON PREPARATION OF AN ENVIRONMENTAL IMPACT STATEMENT (EIS) OR ALTERNATE ASSESSMENT ACTIVITIES

8.1 General Recommendations

It is recommended that no environmental impact statement be prepared since no detrimental environmental effects are foreseen. There are, however, several not well-understood, potential impact areas of uncertain and low operational significance in which a continuing effort should be made. These include (a) lithium lifetime in the upper atmosphere and (b) the lifetime of ions in the plasmasphere at low-latitude distances of 2 to 5 earth radii. Specific limited chemical releases are perhaps paradoxically among the best way to obtain information on (a) and (b) and are recommended.

There is a need for establishing operational procedures which will prevent releases from occurring during the short time intervals when a second spacecraft, susceptible to contamination, is located within the initial expansion cloud of a chemical release at origin distances less than a defined "safe distance." A need for establishing "safe-distance" criteria based on both the release characteristics and contamination thresholds for different spacecraft systems and instruments is implicit in the need for establishing the operational procedures. Technical studies directed toward establishing the "safe-distance" criteria and the operational procedures are accordingly recommended.

8.2 Continuing Efforts

It is recommended that in addition to the two generic recommended chemical release experiments identified in Section 8.1, as well as correlative theoretical work, that contact be maintained with the results of other groups performing on-going chemical releases such as the Defense Nuclear Agency, Department of Energy, etc., in this country and the West Germans, etc., abroad for the purpose of adding any new relevant information. Further contact should be maintained with the results of the environmental assessments for the SPS in particular as regards the lifetime of ions released at low latitudes and distances of 2 to 5 earth radii. The technical analyses directed toward defining "safe-distance" criteria, recommended in Section 8.1 above, should be closely correlated with similar studies which are needed for upper stage rocket firings conducted in the proximity of spacecraft which are susceptible to contamination.

8.3 Public Information Program

The CRM program has a potential for public controversy because of the reaction that might be generated by the sighting of the luminous clouds involved in many of the chemical releases–if there is no public preparation. It is considered that any adverse public response can be virtually eliminated by an active public information program that will reach and inform the population in the appropriate areas prior to conducting a release. It would also be advantageous to inform certain specialized groups, such as radio amateurs and the astronomical community. Such a program has been conducted in the past for specialized chemical release operations and has elicited positive and

favorable response. A representative program as an illustration might be constituted of a complete announcement well in advance (approximately a week) and a detailed announcement shortly (1 to 3 days) before the experiment, emphasizing both the scientific and safety aspects. Following each visible release experiment, an announcement should be made within several hours providing the general results of the test and information on any further experiments.

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APPENDIX A

GENERAL INFORMATION ON THE CHEMICAL RELEASE MODULE PROGRAM

Reprinted from "Chemical Release Module—A Multi-User Facility for Shuttle Spacelab,"
NASA Goddard Space Flight Center, Greenbelt, Maryland, May 1979

Figure A-1. Artist conception of a horizontal red lithium trail (right side) and magnetic field aligned Ba^+ streamers from a sequence of four barium releases (left side) over south-central Canada.

APPENDIX A

CHEMICAL RELEASE MODULE
(A MULTI-USER FACILITY FOR SHUTTLE SPACELAB)

PROGRAM CATEGORY

Solar Terrestrial Multi-User Facility Active Experiments Multiple Missions.

PLANNED LAUNCH TIMES

One or two times each year (1982-1988).

MISSION LIFETIMES

One to six months (each mission).

MISSION FUNCTIONS

Uniquely diagnostic, chemical release experiments are directed toward problems in atmospheric/magnetospheric coupling, space plasma physics, atmospheric dynamics and chemistry, gas dynamics, auroral phenomena, ionospheric communication disturbances, solar wind-magnetosphere interactions, the physics of comets, etc. Chemical releases are a versatile tool for tracing, simulating, and modifying conditions and phenomena in space, and often provide key, breakthrough information that is not attained by other means. The multi-user, multi-mission approach is essential for the many worthy and feasible experiments embracing diverse interests and space locations.

MISSION ELEMENTS

The basic CRM is an expendable Shuttle-launched spacecraft which is reproduced at a low cost for each mission. It interchangeably accomodates a large number of chemical canisters of various types and sizes in response to the specific needs of each experiment. It accommodates propulsion for orbit change in near earth missions.

Standard canisters are provided for the release of a variety of chemicals over a range of release masses. Specialized newly developed canisters, PI instrument packages, etc., are also accommodated.

A reusable, pallet-mounted ejection system is used for near earth missions. SSUS systems are used for missions with distant apogees.

Releases are conducted by command to a flexible decoding system for canister and release time selection in response to near-realtime PI instructions.

Observing stations and networks include surface sites, airborne units, existing spacecraft, and Spacelab instruments. Optical networks are to be organized for mutual support of various experiments and missions.

TYPICAL MISSION ORBITS

A conceptual 12-mission sequence (1982-1988) suggests three "most characteristic" orbits: (1) perigee >200 km, apogee <1200 km, directed toward atmospheric/magnetospheric coupling, field-aligned particle acceleration, and atmospheric experiments, (2) perigee ≥150 km, apogee 3 R_e, keyed to ionospheric conductivity modifications and perturbing the accelerating electric fields in the 2 to 3 R_e range on auroral shells, and (3) apogee at 15 to 25 R_e, keyed to outer magnetosphere, cometary, and solar wind entry experiments but including cold plasma seedings in the middle magnetosphere. An orbit similar to (1), above, is likely for the first mission.

STATUS

Studies by the AMPS Chemical Release Facility Definition Team, with inputs from more than 50 scientists, have been completed. Conceptual design studies have been completed. Category 1 status was received in peer review. A draft of an RFP for final design, fabrication, testing, and integration of the CRM has been prepared. Essential next steps are as follows: the issuance of the RFP and an AO solicitation of experiments.

Science Rationale

Key outstanding questions on the large-scale behavior of our upper atmosphere/ionosphere/magnetosphere environment include the following:

- How and where does solar plasma enter the earth's magnetosphere?
- What fraction of the magnetospheric plasma (a) comes from the solar wind, (b) comes from the ionosphere?
- At what rates and energies and by what processes are ionospheric ions injected into the magnetosphere?
- What are the basic, causative mechanisms producing high-latitude electric fields and auroral phenomena, and will understanding the auroral substorm process automatically yield an understanding of the origin of the radiation belts?
- Is global transport and energy deposition in the thermosphere dominated by high-latitude ion-drag, joule heating, and particle precipitation or by solar photon heating?
- Do solar-weather correlations involve a link via plasma-field processes?

Many of the chemical release experiments proposed address these and similar questions. Release experiments also provide unique approaches to the sub-elements of these questions. This stems from the capabilities for measuring ion and neutral transport, defining the spatial characteristics of regions where charged particles are energized, and the capabilities to simulate natural processes.

The suggested experiments are not, however, confined to large-scale questions. For example, some bear directly on plasma behaviors in our space environment that are important for understanding plasma dynamics. Modeling has been advocated as a means of approaching the complex dynamics which is evident both in the neutral atmosphere and in space plasmas. Chemical releases provide a means for testing model predictions. Relevance also extends to applied problems. An example is the extensive interest in simulating conditions which adversely affect space communications and in testing effects on R-F transmissions under controlled conditions.

Science Objectives and Experiments

The character of chemical release experiments is such that there are one or several specific and definitive objectives in performing each release. Combinations of releases and repetition under different conditions lead to fulfillment of generalized objectives or goals. In select cases a single release operation may be sufficient for testing a concept. The numerous inter- and multi-disciplinary objectives lead to a diversity of usage and modes of approach. For brevity, typical objectives and experiments have been grouped into the six categories below.

Upper Atmosphere Dynamics

Motions of the neutral atmosphere at thermospheric altitudes are caused by electric field ion drag, Joule heating, solar EUV heating, heating by precipitating particles, and tidal forces. They are highly variable on both local and global scales in response to complex combinations of these sources which are both continuous and impulsive. They also exhibit both wave and convective characteristics, and the dissipation of these winds and waves produces a feedback into the causative heating and electromechanical force elements. Historically, vertical wind profiles obtained from rocket releases producing luminous trails have provided most of the information on winds, and because of the indisputable nature of the observations they have been the standard for evaluating other approaches for deducing winds.

The CRM capability for producing luminous tracer trails over any chosen length along its orbital path has opened the possibility of determining the horizontal variability of winds, particularly in the various zones where the driving forces exhibit steep gradients. As trails are observed as a function of time as well as position, wave distortions can also be observed. Wavelengths and both vertical and horizontal amplitudes can be measured. This means that the heretofore elusive gravity wave characteristics can be uniquely determined.

The ambient wind and wave objectives noted above utilize the tracer approach. Simulation and modification approaches appear in experiments designed to create gravity waves and winds and

to experimentally measure parameters such as ion-neutral coupling. The generation of acoustic gravity waves from a point source has received particular attention as a means of definitively determining their propagation characteristics.

Ionospheric Modifications

The objectives motivating various experiments based on either decreasing or increasing the ambient plasma density by means of a chemical release include: (a) obtaining measurements of the rate of refilling after creation of a plasma depletion "hole" as a means of studying ambient ionization processes, (b) studying the magnetic field aligned propagation of VLF waves by creating a propagation duct, (c) simulating the formation and movement of the natural depletion "bubbles" which occur over the magnetic equator, (d) investigations of reaction rates, recombination coefficients, airglow production, etc., and (e) creating the conditions for inducing selected plasma instabilities to produce ionospheric irregularities and spread-F conditions. The science objectives in these experiments have a direct bearing on communication problems. Other forms of ionospheric modification are directed toward studying ionospheric/magnetospheric coupling and testing plasma theories.

Exploratory Plasma Physics

Chemical releases make it possible to study complex magnetospheric plasma processes by introducing controlled perturbations under well-defined initial conditions, and measuring the resulting system response. An example which has been the subject of extensive theoretical modeling is the seeding of the equatorial magnetosphere with cold lithium plasma to reduce the resonant energy required to drive electron and proton cyclotron instabilities. The anticipated result is wave amplification and precipitation of trapped electrons and ring current protons. Recently, the interest in seeding has been extended to the 2 to 3 R_e altitude range along shells where auroral particle acceleration processes are now known to exist. The effective process, or mechanism, is, however, unresolved and theories are controversial. Perturbing this region by overseeding with ions represents an exploratory experiment in which one seeks to learn by disrupting the potential distribution in the field-aligned circuit. This approach is complementary to the tracer experiments noted below.

The exploratory objectives are not confined to ionospheric and magnetospheric phenomena. For example, the creation of an artificial comet in the solar wind would permit study of the trapping of the interplanetary magnetic field, the formation of cometary rays, their dragging into the tail axes, and the gradual erosion of the cometary ions. This involves a large-scale release at a large distance. Another example, performable near the earth with a modest release, is the testing of the critical velocity hypothesis introduced by Alfven in his theory of origin of the solar system. This hypothesis states that when the relative bulk velocity of a plasma and a neutral gas exceeds a critical value in flow transverse to the magnetic field, the plasma will decelerate and the neutral gas will rapidly ionize. Using high mass neutral particles having a low ionization potential one can test this hypothesis with releases at orbital velocity.

Ionosphere/Magnetosphere Coupling

Recognition that the upper atmosphere, ionosphere, and magnetosphere behave as a single, strongly coupled system with complex internal feedback relationships has closely paralleled advances in our knowledge of space electric fields and their associated electric current systems. Electric field-driven ion drag is, for example, the strongest force driving upper atmosphere winds. Coupling studies thus center on electric field studies, and the use of visible ion tracers is unique for obtaining the 3-dimensional distribution of electric fields as a function of time. Individual objectives using ion tracers are thus as numerous as the regions and conditions of special interest, many of which are at auroral latitudes where the energy exchange is maximum. Particular emphasis is directed toward obtaining the distribution of electric fields along magnetic field lines which intersect aurora. Conflicting evidence and theories exist as to whether these fields are weakly distributed over many thousands of kilometers or concentrated in narrow altitude zones, or both. One can address this question definitively by "painting" field lines with visible ions and observing the changes in the distribution of the ions with time. Because of the dispersing effect of the $\mu \nabla B$ "mirror force" the initial "painting" or distribution can extend over many thousands of kilometers from isotropic releases at any altitude above 900 km. The relevance of the E-parallel distribution applies two ways: (a) it determines the precipitation causing aurora, and (b) it injects ionospheric ions, such as O^+, into the magnetosphere where they then become a major constituent in the trapped population that produces the ring current encircling the earth. Ionosphere/magnetosphere exchange is not, however, confined to auroral regions. Although the cause is not clear it is known that light ions are also depleted in a trough region adjacent to the auroral belt and that there is an inter-hemispherical exchange of ionization along magnetic field lines at much lower latitudes. The sensitive tracer approach applies to these problems as well and to related objectives in which the cause of composition anomalies is sought.

The principal impedance to the flow of the 10^4 to 10^6 amperes flowing in the high-latitude, ionospheric/magnetospheric circuit occurs within the ionosphere. It is a load on the magnetospheric generator, but there is uncertainty as to whether this generator is primarily a voltage generator or a current generator. As in any power circuit changing the electric load becomes a diagnostic approach to determining the generator characteristics. With this objective a number of conductivity modification experiments have been proposed in which the release locally alters the electrical state of the plasma in order to observe the effects of the change. Approaches range from both ion density increases and decreases to mechanical (i.e., "dynamo") movement of the ionization by momentum transfer.

Solar Plasma—Entry, Flow, and Energization

Finding answers to the basic questions "where and how does solar wind plasma enter the magnetosphere," "what is its subsequent flow," and "where and how is it energized in the magnetosphere" has been an elusive goal in space physics. The release of tracer ions outside the magnetosphere with optical tracking and the subsequent detection and energy analysis of the tracer elements within the magnetosphere provides one of the few, if not only, methods of obtaining unambiguous answers to some of these questions. Releases in the high-latitude magnetosheath near the cusp and at low-latitude locations along the flanks of the magnetotail appear most promising for obtaining entry

but the generality of the entry question also needs to be examined with releases near the sub-solar point. Tracer releases at selected locations within the outer magnetosphere will identify the subsequent transport and energization. As fast convection (i.e., transport transverse to the magnetic field) is known to exist in the plasma mantle, adjacent to the magnetopause, and in the magnetotail plasma sheet, these become logical choices for initial release investigations.

Photochemistry and Chemical Reactions

The objectives motivating specific experiments stem from questions related to the following: (1) the photochemical fragmentation of cometary molecules, (2) the solar photolysis and cross-sections for molecular reactions of particular interest in mesospheric-stratospheric regions, (3) the atmospheric chemistry of other planets, and (4) the optimum performance of ionospheric modification experiments. Important factors are the use of the actual, rather than laboratory simulated, sun and the absence of wall collisions for reactions involving metastable and pre-excited states. Photodissociation studies in which a selected gas is released from the CRM and measurements of the solar absorption spectra are made from the shuttle have been most frequently noted. Several gases (CO_2, CO, and H_2O) are of interest to both cometary and planetary atmosphere studies and also find application in ionospheric modification experiments. Other interests include the following: the derivatives of C_2H_2 and HCN (comet studies), the products of chlorine and nitrogen compounds (stratospheric studies), and simulations of atomic oxygen beams at orbital velocities.

Approach

The need for a large-scale, general purpose, multi-user, modular chemical release facility to accomplish the numerous and multi-disciplinary objectives typified above comes from the following factors:

1. The number of experiments defined or suggested is both large and growing.

2. Maximum mass carrying capacity is desirable to support the demands for both large numbers of small releases and requirements for large releases.

3. Costs per experiment, and costs per unit mass released, decrease greatly with increasing canister and mass carrying capacity. Stemming from the relatively low cost of canister fabrication large chemical-release payloads are inherently low in cost per unit mass. This characteristic is particularly well matched to shuttle capabilities.

4. Canister design and fabrication is, in general, a specialized industrial, rather than PI capability; thus, canisters in most cases must be furnished. Standardized canisters will satisfy a large fraction of the requirements. The use of standard canisters minimizes qualification and integration costs.

5. An adaptable modular design is required: (a) to accommodate standard canisters of various sizes, specialized canisters and tanks, instrumented submodules, ejection options, etc., (b) to

make these accommodations interchangeable, and (c) to meet the requirements for a diversity of missions and use of different propulsion motors.

6. Flexible operational modes and lifetimes are required for selecting release types and masses and the scheduling of releases relative to the required observations and diagnostics.

These factors influence the design (described later) and limit PI participation in pre-flight payload activities to that of specifying requirements, except for special needs as noted in Table A-1. Just as it is clear that releases must be provided for the Principal Investigator, it is equally clear that performance of a release for a particular experiment must be controlled by the Principal Investigator.

Table A-1
Principal Investigator Functions

1. Proposes experiment

   a. Specifies the type of release (chemical, mass, duration, sequence, etc.).

   b. Specifies the release location and conditions.

   c. Provides payload hardware only for special, nonstandard needs.

2. Is responsible for conducting or negotiating arrangements for the required observations.

3. Is responsible for designating release times and making GO/NO-GO decisions.

4. Is responsible for data analysis and interpretation.

Item 2, Table A-1, does not imply that each experiment will require an independent set of observing instruments. Coordination of PI observing needs and capabilities should result in common usage of observing instruments and facilities.

Conceptual Mission Sequence

Mission and experiment selections, numbers and sequences of missions, and launch schedules have not been determined and are subject to program reviews and approvals. Planning exercises oriented toward accommodating known potential experiments and their different mission/orbit requirements have, however, been conducted. Tables A-2 and A-3 represent the skeleton of one plan which illustrates a step-by-step progression in meeting general requirements without going into specific experiment assignments. A large number of important experiments can be performed which do not require any new release technology or specialized supporting equipment. The first mission is directed toward accommodating as many of these experiments as possible for maximum results on the shortest schedule. A 1982 launch would also permit experiments coordinated with DE-A, B satellite measurements. A second, more arbitrary, aspect of this particular plan is that it places launches requiring large (i.e., >100 kg, each) modification/perturbation releases on missions separate from

those which require a multiplicity of small (i.e., ≤20 kg) releases. This split is not essential in terms of CRM design; it is introduced from cost and schedule considerations.

Table A-2
Conceptual Mission Evolution

Mission	Technical/Operational Sequence
1	(1) Use proven canisters and chemicals.
	(2) Select well defined objectives and approaches.
2 and 3	(1) Include new release chemicals and canister designs.
	(2) Include more exploratory experiments.
4 and 5	(1) Utilize SSUS-A vehicle.
	(2) Include ejectable instrumented submodules.
6 and 7	(1) Use WTR launch for:
	(a) polar cap experiments.
	(b) auroral experiments in Alaska and Scandinavia sectors.
8 and 9	(1) Large-scale solar wind entry (OPEN).
	(2) Comet simulation.
10,11, and 12	Follow-on missions: New developments and repeats.

CRM Characteristics

The CRM (Flight) facility embraces the CRM bus, chemical release canisters (payload), small-scale propulsion motors, a pallet mount and ejection system, adapter units for mating with SSUS vehicles, and shuttle and ground support equipment and software. The CRM bus accommodates all payload elements and provides the basic R-F and electrical systems for commands, telemetry, tracking, command decoding, data handling, power, attitude determination, status and housekeeping sensing, and system controls. R-F systems are based on TDRSS compatibility. Compatibility with shuttle payload accommodation requirements, interfaces, and safety policies has been established in conceptual design studies.

Table A-3
Conceptual Mission Schedule

(A) Primarily Small/Medium Scale Release Experiments

Mission Number	Launch Site	Incl.	Approximate Orbit Perigee (km)	Apogee (km)	Shuttle Mount	Launch Date
1	ETR	57°	⩾200	<1200	Pallet	1982
3	ETR	57°	⩾200	<1200	Pallet	1983
5	ETR	Low	>200	15 R_e	SSUS-A	1984
6	ETR	Polar	⩾200	<1200	Pallet	1985
10-12	Follow-On					1987-1988

(B) Primarily Large Release Perturbation/Modification Experiments

2	ETR	⩾32°	>200	<500	Pallet	1983
4	ETR	57°	⩾150	>2 R_e	SSUS-A	1984
7	WTR	Polar	⩾200	<1200	Pallet	1985
8-9	ETR	Low	>200	>15 R_e	SSUS-A	1986

Payload accommodations provide the capability to conduct: (a) a large number of small thermite releases and/or a smaller number of large thermite releases of both short (point) and long (trail) duration types, (b) tank releases of liquids or gases, (c) shaped charge releases from ejected sub-modules, (d) releases from ejected thermite canisters, (e) diagnostic measurements with PI instruments on board, and (f) diagnostic measurements from ejected PI instrumented sub-modules. The payload mass carrying capability is indicated by Table A-4, which takes into account all interface structure and CRM bus weights, but does not include propulsion motors, in arriving at the weight available for experiment installation. Two CRM's are stacked in the case quoted using the SSUS-A cradle.

The numbers in Table A-4 assume installation of relatively dense solid thermite release hardware. With diverse experiment packages having different shapes and volumes the numbers decrease. As a general guideline it is anticipated that payload weights ⩾1000 kg will be accommodated on all missions.

Table A-4
Payload Weight Allowance (Direct Ejection)

Installed On	Weight Limit (kg)	Experiment Weight Capacity (kg)
Pallet	3000	2000
SSUS-D Cradle	3400	2300
SSUS-A Cradle	6270	4360

As conceptually designed, flexibility in the CRM accomodations is achieved using either: (a) a hexagonal array of eight rectangular and triangular experiment bays (sub-module boxes or open areas), or (b) a single "doughnut" sub-module which is modularized into eight experiment bays (Note: a choice between these options has not been made). These sub-modules fit peripherally around a cylindrical center module which accommodates all electrical systems and serves as the main load-carrying structure. This center structure is hollow, with a clear diameter of 1.01 meters. For kick motor installation this accommodates all presently qualified solid propellant motors smaller than the SSUS motors.

There are also provisions for axial experiment sub-modules opposite the kick motor or along both the + and - spin axes when a kick motor is not used. Annular solar cell rings mounted off the ends of the center structure provide power for an indefinitely long lifetime. The 3-meter diameter of the CRM provides "flywheel" spin stability and fits within the envelope of one pallet.

Observing Operations

The observations required by the various experiments are both diverse and similar. The observational matrix, indicated without cross-referencing in Table A-5, is thus complex.

Table A-5
Observing Modes and Techniques

Modes	Techniques
Permanent observatories	(a) Optical
Temporary surface stations	(b) R-F
Aircraft	(c) Mass spectrometers
Sounding rockets	(d) Field and plasma diagnostic instruments
Explorer satellites	
Shuttle sub-satellites	
On-board shuttle instruments	
CRM ejected sub-modules	
CRM instruments	

A high percent of potential experiments require surface and/or aircraft optical imaging (film, video, etc.) as either prime or supporting data and a significant, but lesser, fraction require or benefit from surface photometeric or R-F observations. Operational planning, prior to experiment selection, has thus been directed primarily toward the commonality of these forms of surface observations. The goal is to achieve maximum utilization of existing instruments and/or facilities and thus avoid a proliferation of instrument procurements and observing networks with duplicate functions. Conceptually, temporary but reoccupied networks could be established in several key areas to support a large fraction of the low-altitude release experiments. Suggested examples include areas centered on Arecibo, Puerto Rico and Jicamarca, Peru for experiments at low latitudes and at the magnetic equator, respectively. Prior to WTR launches, the region south of the Churchill, Canada Rocket Range is the logical choice for auroral belt experiments. Experiments which produce visible tracers along magnetic field lines from that region can also be supported by optical observing sites in the southwest U.S. Key areas centered on observing capabilities in Alaska and the EISCAT facility in northern Europe appear likely for WTR launches. When integrated with the use of Spacelab and aircraft observing facilities, these concepts suggest that an extensive data base could be provided as a service to PI's. They also reduce the potential costs of the observing effort.

Program Schedule

A first mission launch in 1982, as conceptually shown in Table A-3, would make it possible to use instruments on the DE satellites as tracer particle detectors and provide other correlations for selected objectives. Achievement of a 1982 launch is dependent on initiating CRM development in the first half of 1980 and using proven canister designs for the first mission. The modular design is such that the experiment selections do not have to occur prior to initiating the development. It is anticipated that the conceptual 12 mission sequence, outlined above, will not be adequate to support all worthy and feasible experiments. Organization into experiment teams following selections appears desirable.

Chemical Release Facility Definition Team

Members of the "Chemical Release Facility Definition Team" of the "AMPS Science Definition Working Group" are listed below.

Leader:	J. P. Heppner	Goddard Space Flight Center
Co-Leader:	R. W. McEntire	JHU/Applied Physics Laboratory
	T. N. Davis	University of Alaska
	G. Haerendel	Max Planck Institut fur Extraterrestrial Physiks
	L. M. Linson	Science Applications Inc.
	H. A. Taylor/H. C. Brinton	Goddard Space Flight Center
	G. D. Thome	Raytheon Co.
	D. J. Williams/D. S. Evans	NOAA Environmental Research Laboratory

Their detailed study report entitled "Chemical Release Module: A Multi-User Facility for Shuttle Spacelab" was completed in March 1978.

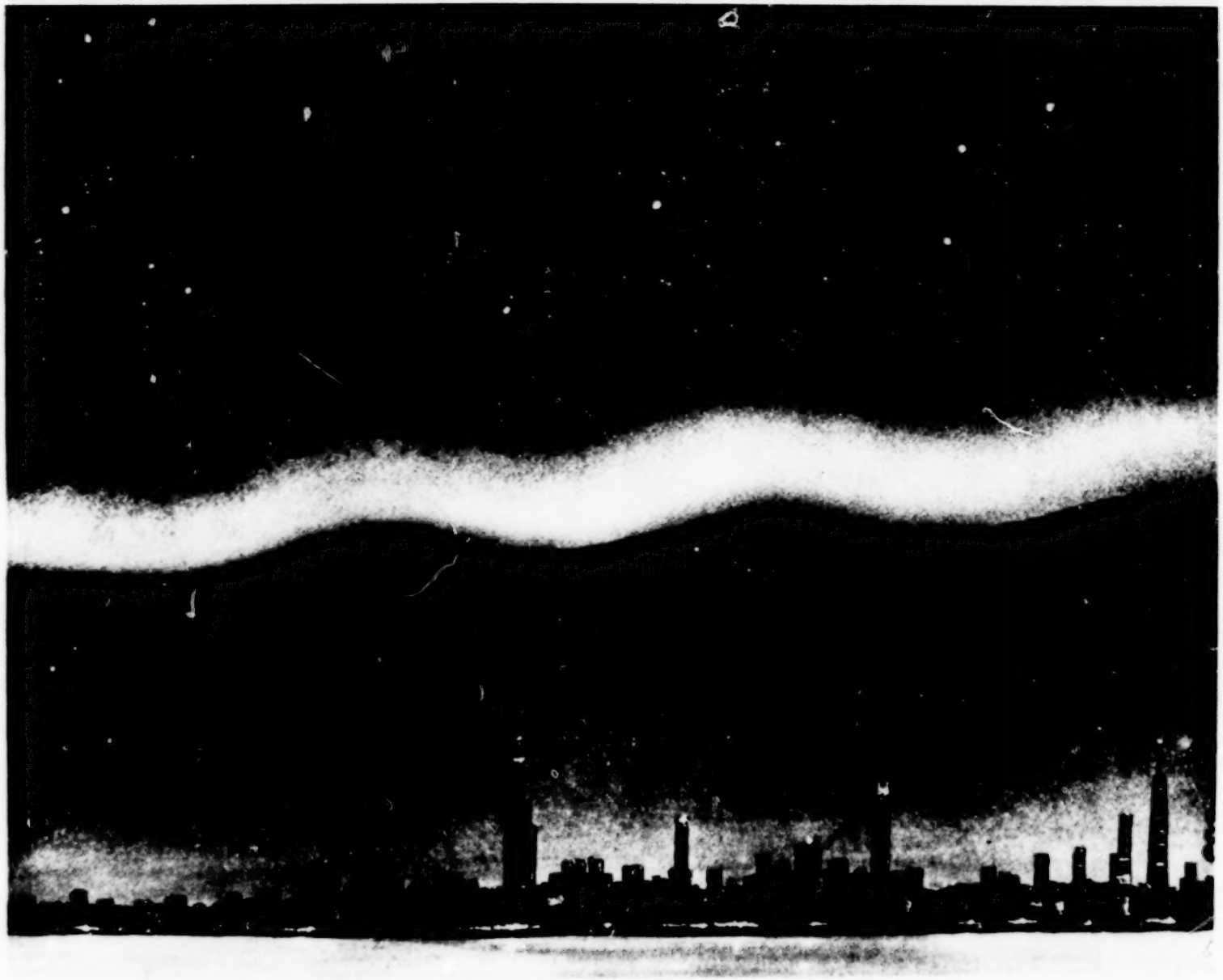

Figure A-2. Artist conception of gravity wave distortion of a neutral lithium trail as seen over the Chicago skyline.

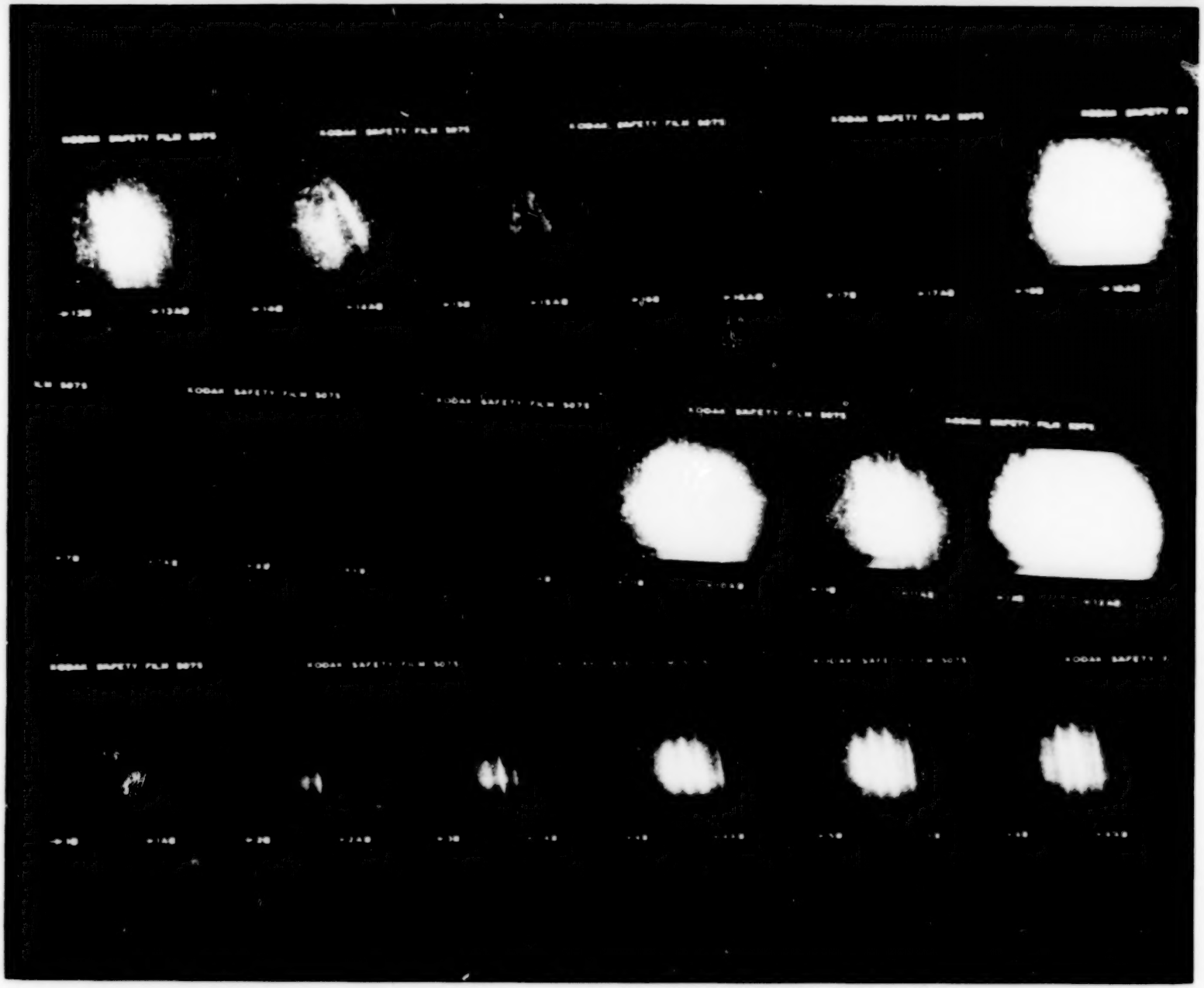

Figure A-3. 35 mm photo sequence of Ba^+ streamers from a Project Cameo releases at latitude 74° to 79° as observed from Richland, Washington (lat. 46°). Releases were below the horizon (lower left) at an altitude of 960 km. The Ba^+ streamers reached lengths of 10000 km and were last seen from Hawaii at distances >6 R_e.

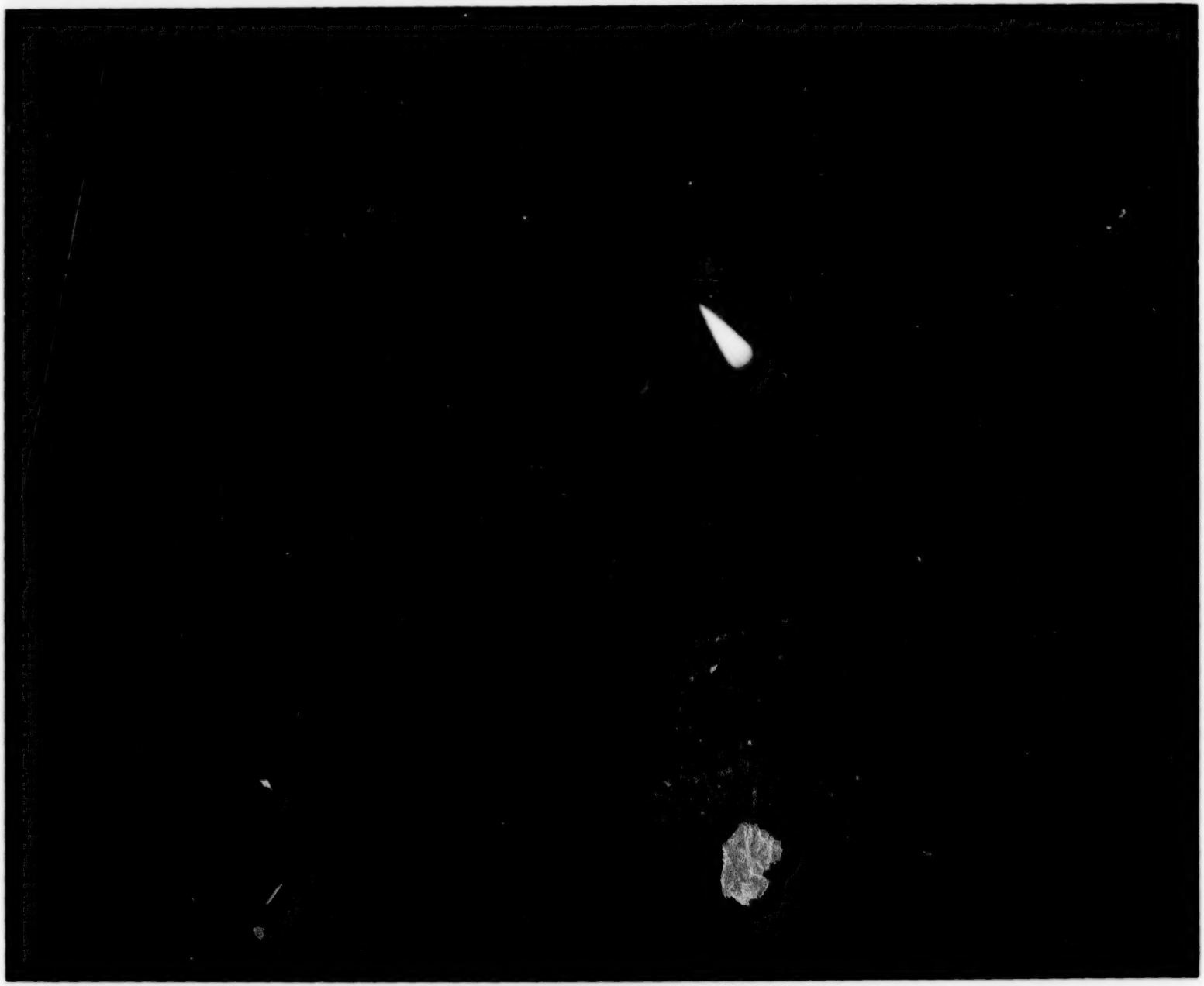

Figure A-4. Exposure from Pt. Barrow, Alaska at time of fourth Cameo barium release. Showing (from left to right) field aligned ion clouds from second and third release, spherically expanding neutral clouds, and the plume of the fourth release.

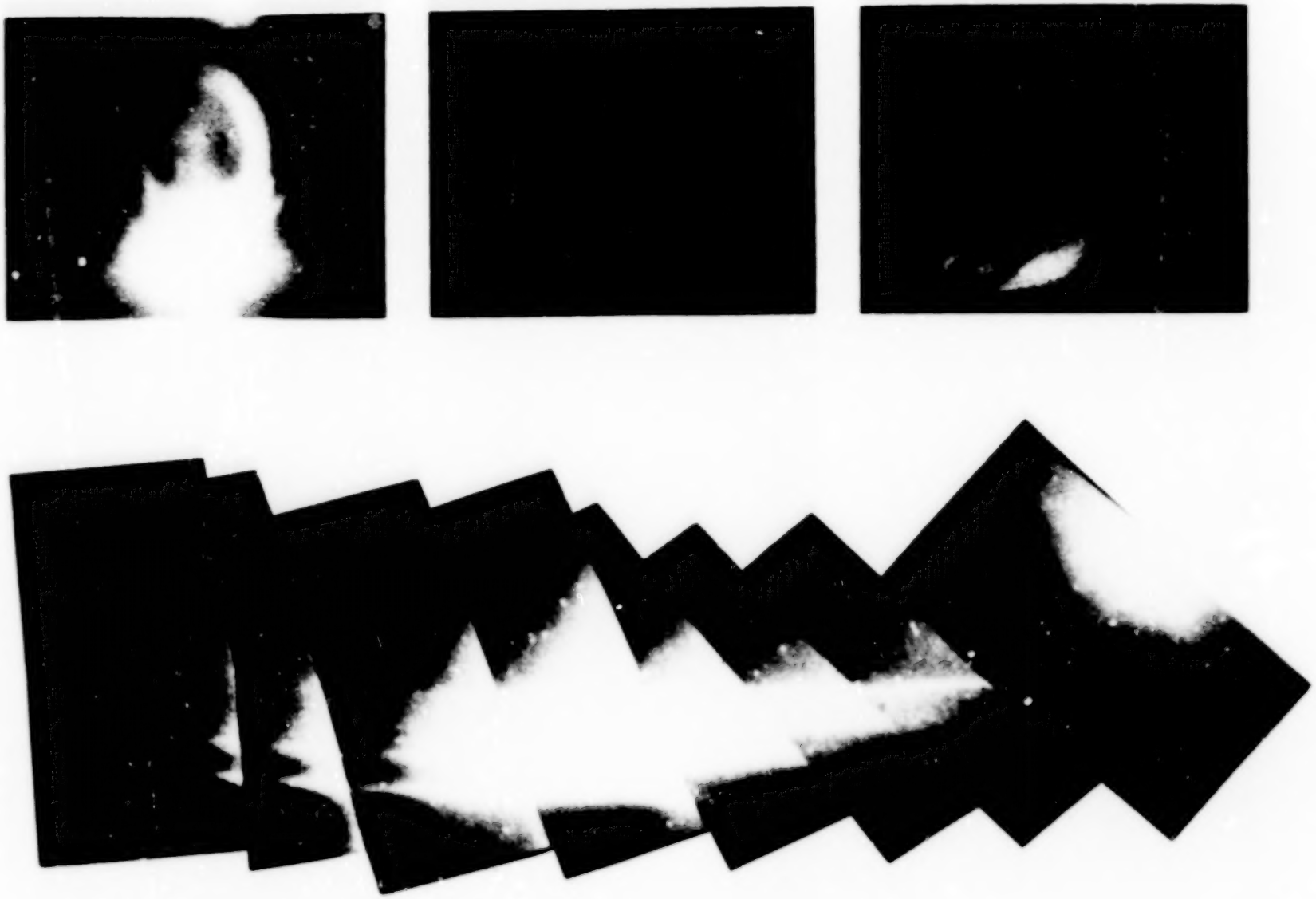

Figure A-5. Television scan of Ba^{+} streamers from Cameo releases taken from a NASA Lear jet.

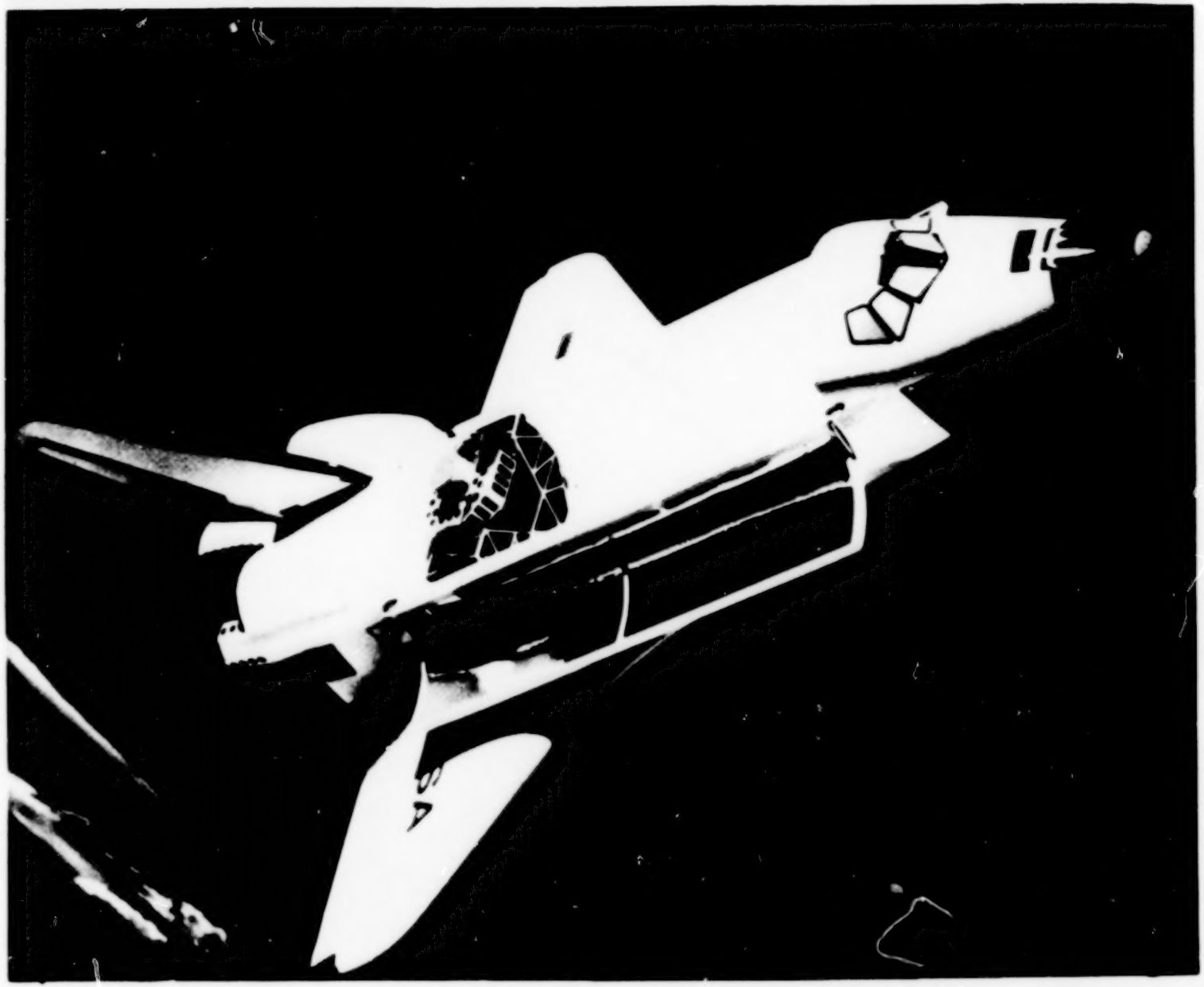

Figure A-6. Model CRM mounted in shuttle bay.

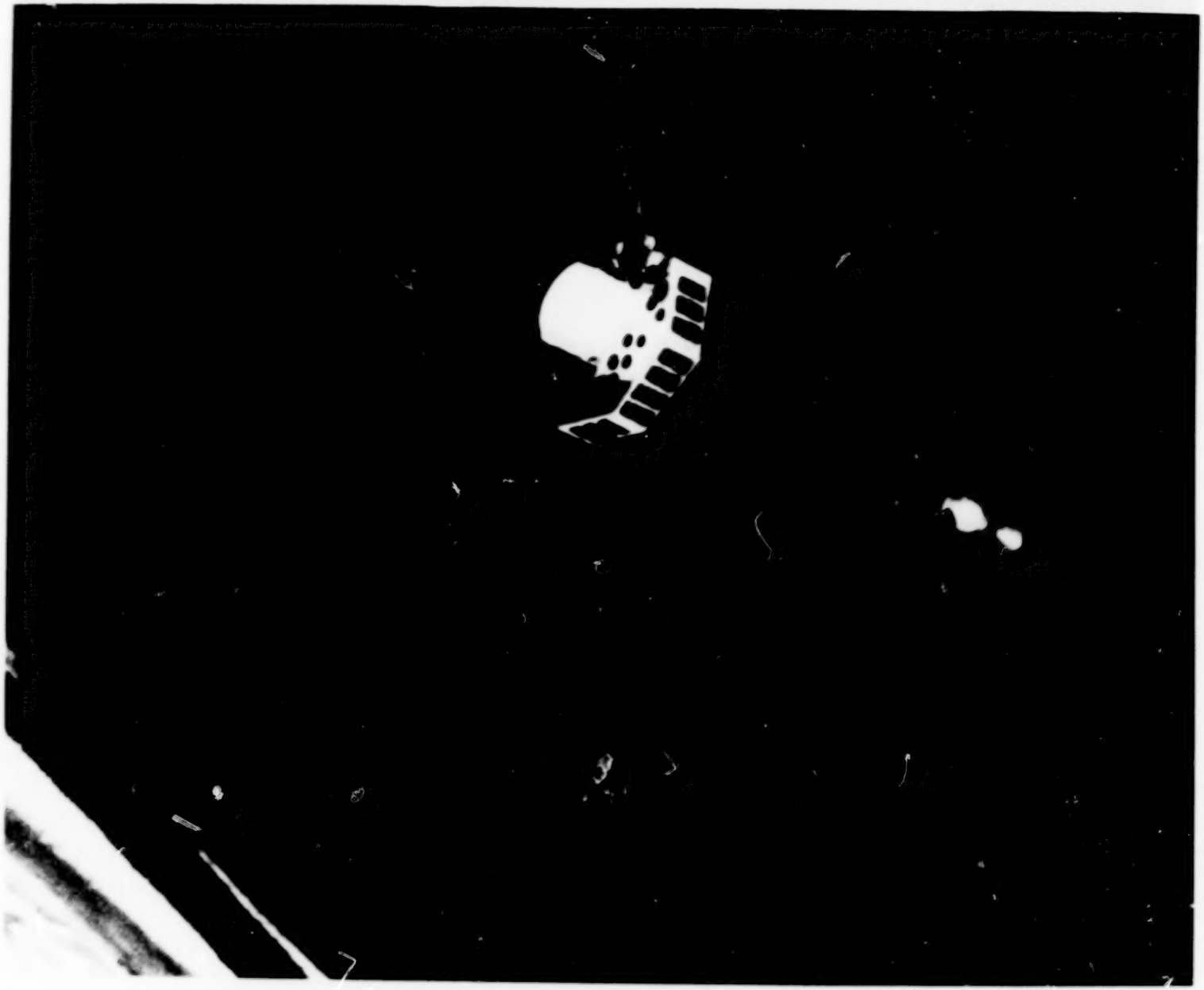

Figure A-7. Model CRM leaving kick motor.

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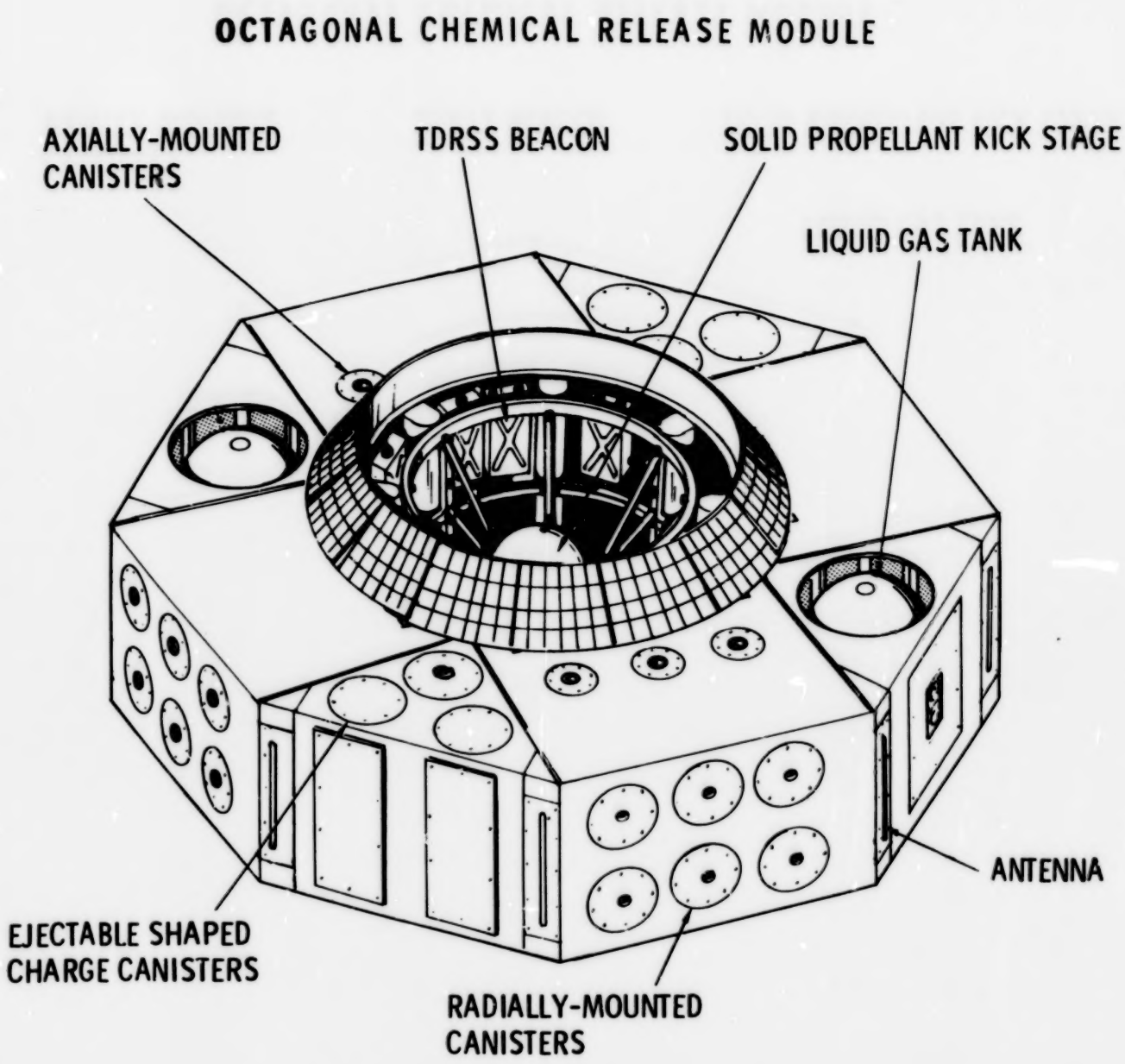

Figure A-8. Conceptual octagonal CRM configuration, diameter = 3 meters.

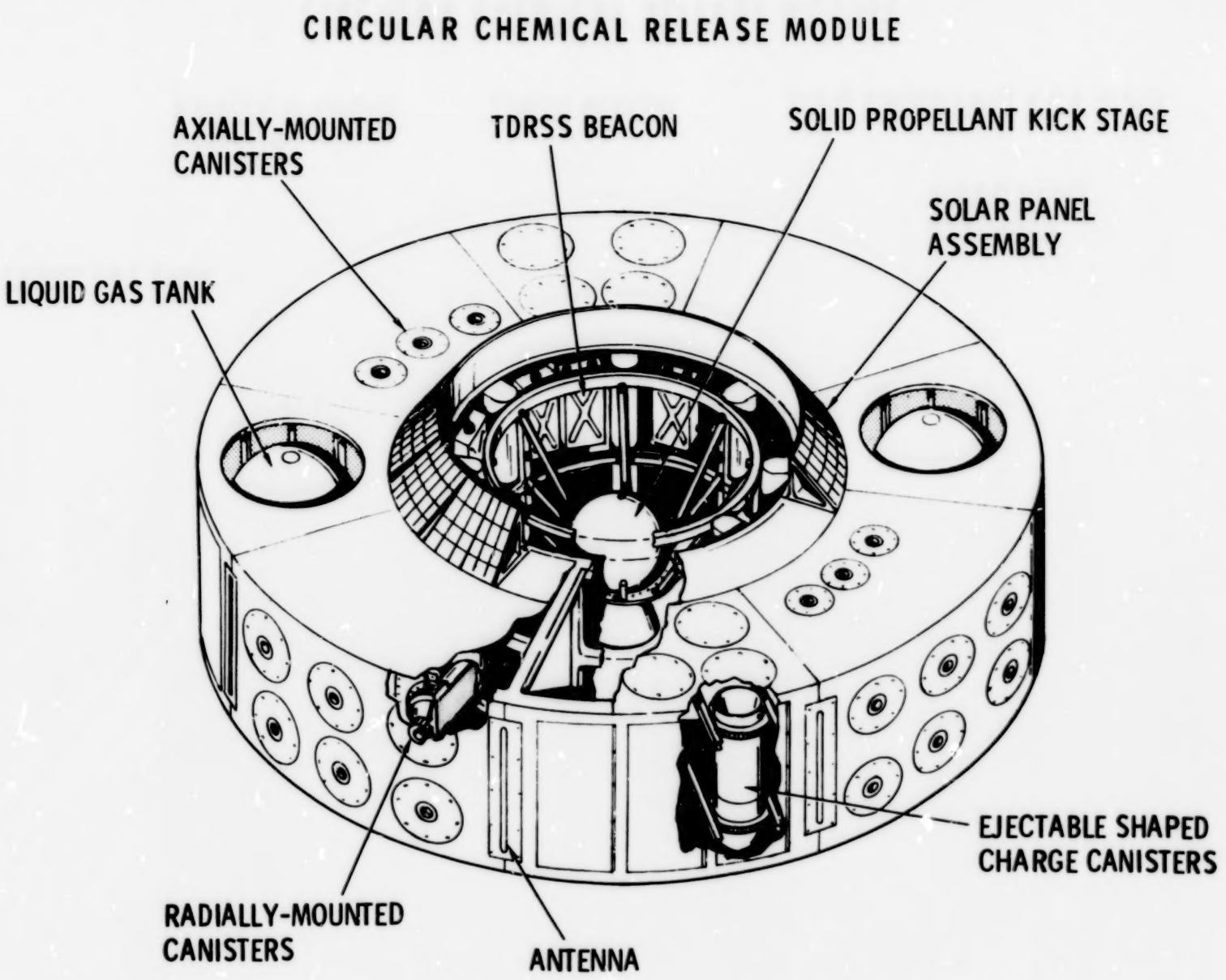

Figure A-9. Conceptual circular CRM configuration, diameter = 3 meters.

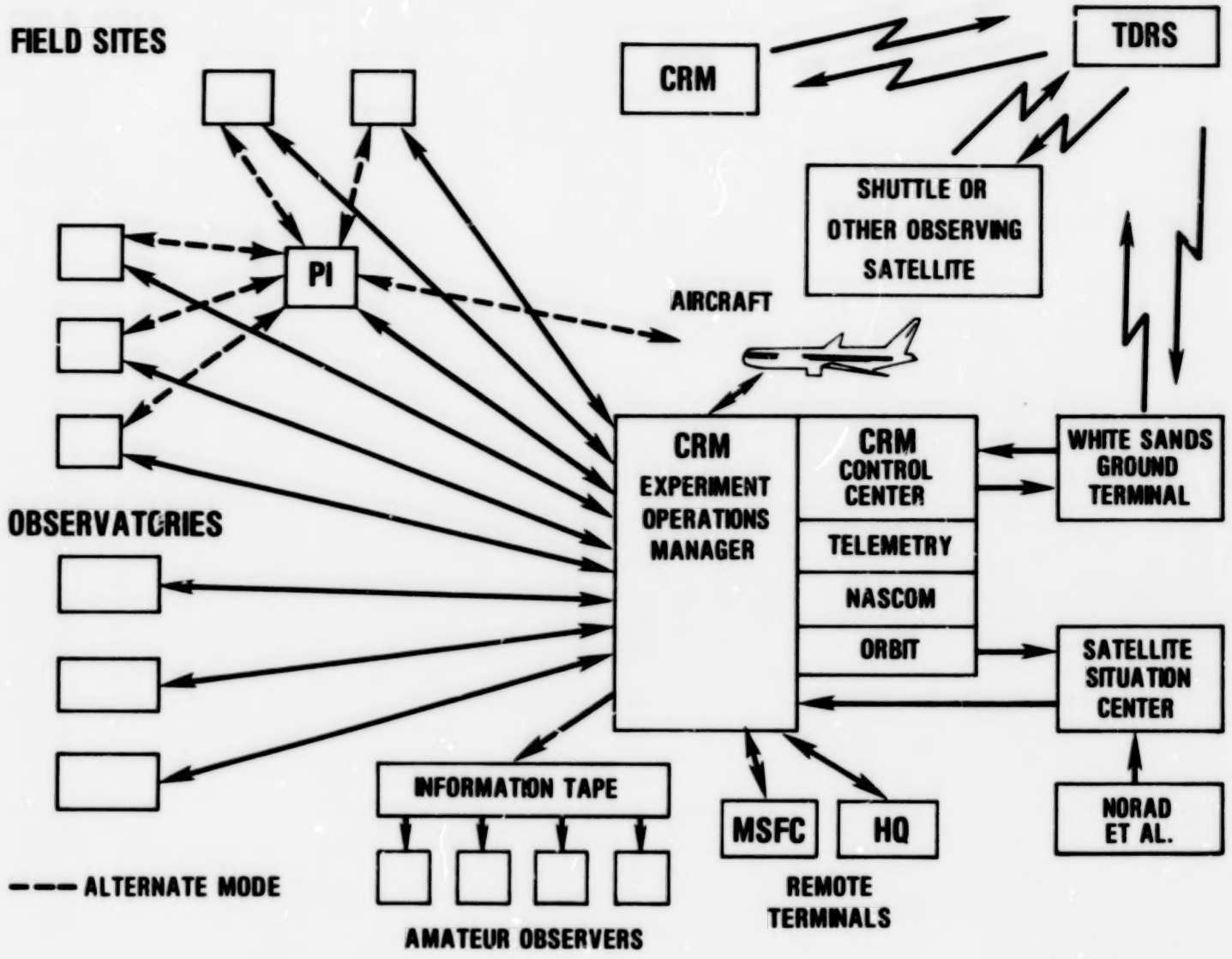

Figure A-10. Communication links for a typical CRM releases decision.

APPENDIX B

CHEMICAL RELEASE HISTORY AND BACKGROUND

This Appendix briefly summarizes some of the record of chemical releases into the atmosphere. Section 1 gives a partial log of some of the many chemical releases, particularly ionic, together with a recapitulation of launch location for previous chemical release payloads and approximate altitude distribution. The art and practice of manufacturing payloads is given in a series of Thiokol documents (Sources 1.40 to 1.42) and summarized in Source 1.3 and is not discussed here. Section 2 furnishes a recapitulation of the present theory of the initial dispersion and notes its general applicability. Specific theories of the individual phenomenology, e.g., electron depletion etc., are discussed briefly and/or referenced in the main text and not in the appendix.

CHEMICAL RELEASE HISTORY AND BACKGROUND

Since the original chemical releases of Marmo, Pressman, et al. in the late 1950's (Sources 1.5 to 1.12) over 350 chemical releases have been performed with a large variety of compounds (See Tables B-1 to B-3, Figures B-1 and B-2) at heights from 80 km to 12 earth radii and at weights up to 320 kg. The objectives have included wind, diffusion, and turbulence measurements, electron enhancement of depletion, communication and airglow studies, auroral studies, etc. In particular many barium releases from rockets have been conducted in the ionosphere, worldwide, primarily to measure ambient electric fields using small releases (< 4 kg) at high altitude (> 200 km) and to produce enhancements in the ionospheric electron concentration using large releases (16 kg to 320 kg) at lower altitudes (< 200 km). The properties of the larger releases have been studied extensively using a variety of radar, optical, propagation path, and rocket probe techniques. As a result, many characteristics of these releases, such as the time development of the scale size of the neutral clouds, peak electron concentration, and distribution of barium ions perpendicular and parallel to the magnetic field are well documented and the behavior is understood. In the following table lists are given of selected and representative chemical release experiments: Table B-1–Summary of Goddard Space Flight Center (GSFC) Chemical Releases; Table B-2–List of Barium and Other Ion Chemical Releases (1968-1979); and Table B-3–List of Ion Cloud Releases with Experimental Parameters (1968-1971).

Additionally in Figures B-1 and B-2 respectively the launch locations for past chemical release payloads and the approximate altitude distribution for chemical releases (previous experiments) amounting conservatively to more than 4000 kg of chemicals are given. Involved in this effort in the United States have been such organizations as the National Aeronautics and Space Administration, the Air Force Cambridge Research Laboratory, the Defense Nuclear Agency, the Naval Research Laboratory, the Los Alamos Scientific Laboratory and university groups such as the University of Alaska. Abroad, the contributions of the Max Planck Institute in Germany have been extensive. Contributions from other countries include: England (University College, London), France (University of Paris), Canada, Denmark, Italy, Holland, USSR, Norway, Sweden and India, with no attempt at exhaustiveness in this list.

Table B-1
Summary of GSFC Chemical Releases

Year	Launch Site or Location	Rocket	Number of Rockets	Number of Barium Releases	Other Releases
1967	Wallops Island, VA	Nike-Tomahawk	1	3	
1967	Andennes, Norway	Nike-Tomahawk	3	12	
1968	Andennes, Norway	Nike-Tomahawk	3	12	
1969	Cape Perry, Canada	Nike-Tomahawk	3	12	
1970	Barter Island, AK	Nike-Tomahawk	3	12	
1970	Poker Flats, AK	Nike-Tomahawk	3	12	
1971	Hall Beach, Canada	Nike-Tomahawk	4	16	
1972	Poker Flats, AK	Nike-Tomahawk	3	12	4 TMA/TEA trails
1973	Poker Flats, AK	Nike-Tomahawk	5	10	
1974	Poker Flats, AK	Nike-Tomahawk	3	12	3 TMA/TEA trails
1975	Poker Flats, AK	Nike-Tomahawk	3	12	3 TMA/TEA trails
1976	Poker Flats, AK	Nike-Tomahawk	4	12	2 TMA/TEA trails 2 Lithium trails
1978	74-80°, 110-140°W	Delta 2nd Stage	1	4	
1978	Scandinavia	Delta 2nd Stage	1		1 Lithium
1979	Poker Flats, AK	Terrier-Malemute	1	3	4 Lithium trails
1979	Poker Flats, AK	Nike-Tomahawk	1	2	2 Lithium trails

NOTE: Barium releases usually include 1-2% strontium, several include sodium or lithium doping. Lithium trails sometimes include sodium.

Table B-2
List of Barium and Other Ion Cloud Releases (1968-1979)

Operation	Event	Date	Location	Purpose	
Secede	Apple	4 May 1968, AM	Puerto Rico	Barium Thermite Release	Yes
	Birch	7 May 1968, AM	Puerto Rico	Barium Thermite Release	Yes
	Cherry	2 May 1968, AM	Puerto Rico	Barium Thermite Release	Rocket Failure
	Dogwood	13 May 1968, AM	Puerto Rico	Barium Thermite Release	Yes
Secede III	Juniper	5 March 1969, PM	Alaska	Barium Thermite Release*	Yes
	Elm	6 March 1969, PM	Alaska	Barium Thermite Release*	Yes
	Ironwood	11 March 1969, AM	Alaska	Barium Thermite Release*	Yes
	Fir	15 March 1969, PM	Alaska	Barium Thermite Release	Yes
	Gum	19 March 1969, PM	Alaska	Barium Thermite Release	Yes
	Hemlock	20 March 1969, PM	Alaska	Barium Thermite Release	Yes
Birdseed I	Roadrunner	16 May 1970, PM	Hawaii	Barium Thermite Release	Yes
	Sapsucker	26 May 1970, PM	Hawaii	Barium Thermite Release	Yes
	Duck	26 May 1970, PM	Hawaii	Neon Plasma Gun	Yes
	Titmouse	6 June 1970, PM	Hawaii	Barium Thermite Release	Yes
	Egret	6 June 1970, PM	Hawaii	Neon Plasma Gun	Yes
Secede II	Nutmeg	16 January 1971, PM	Florida	Barium Thermite Release	Yes
	Plum	20 January 1971, PM	Florida	Barium Thermite Release	Yes
	Redwood	26 January 1971, PM	Florida	Barium Thermite Release	Yes
	Olive	29 January 1971, PM	Florida	Barium Thermite Release*	Yes
	Spruce	1 February 1971, PM	Florida	Barium Thermite Release	Yes
Barbizon	Alco	18 October 1971, AM	Hawaii	Barium Field Line Tracing	Yes
	Bubia	19 October 1971, AM	Hawaii	Barium Field Line Tracing	Yes
	NASA	23 October 1971, AM	Hawaii	Electron Gun	Power Supply Failure
	Canuto	24 October 1971, PM	Hawaii	Barium Thermite Release*	Yes
	J-16 EMP	30 October 1971, AM	Hawaii	EMP	No
	Espatula	5 November 1971, AM	Hawaii	Ferrocene Release	Rocket Failure
	Dardabasi	8 November 1971, PM	Hawaii	Barium Thermite Release*	Yes
	Buitre	8 November 1971, PM	Hawaii	Neon Plasma Gun	Yes

*Multiple release

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Table B-2 (continued)
List of Barium and Other Ion Cloud Releases (1968-1979)

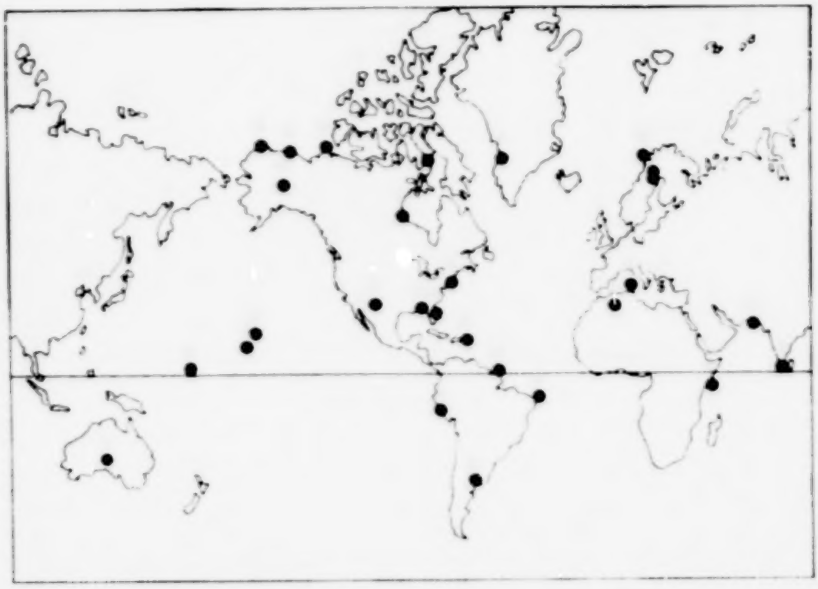
Operation	Event	Date	Location	Purpose	
Febe		3 February 1972, PM	Nevada	Ferrocene Release	Yes
Oosik		7 March 1972, PM	Alaska	Barium Field Line Tracing	No
Picaposte	Chachalaca	9 October 1972, AM	Alaska	Barium Field Line Tracing	Yes
	Faison	11 October 1972, AM	Alaska	Barium Field Line Tracing	Rocket Failure
	NASA	15 October 1972, AM	Hawaii	Electron Gun	Yes
	Loro	18 October 1972, AM	Hawaii	Barium Field Line Tracing	Yes
	Halcon	20 October 1972, AM	Hawaii	Lithium Deposition	Rocket Failure
	Gayo	27 October 1972, PM	Hawaii	Ferrocene Release	Yes
	Tirano		Hawaii	EMP	Scrubbed
	Rctv	30 October 1972, PM	Hawaii	Re-Entry Vehicle	Yes
Skylab	Skylab I	27 November 1973, AM	Alaska	Barium Field Line Tracing	Yes
	Skylab II	4 December 1973, AM	Alaska	Barium Field Line Tracing	Yes
Cotinga	Ispida	16 March 1974, AM	Alaska	Barium Field Line Tracing	Yes
	Oca	23 March 1974, PM	Alaska	Barium Field Line Tracing	Rocket Failure
	Acanta		Alaska	Barium Field Line Tracing	Damaged on Pad

Table B-2 (continued)
List of Barium and Other Ion Cloud Releases (1968-1979)

Operation	Event	Date	Location	Purpose
Tordo	Tordo-I	6 January 75 PM	Cape Perry	Barium Field Line Tracing
	Tordo-II	16 January 75 PM	Cape Perry	Barium Field Line Tracing
Loxia	Loxia	14 May 75 PM	Hawaii	Barium Field Line Tracing
Perquito	Perquito Uno	25 November 75 PM	Cape Perry	Barium Field Line Tracing
	Perquito Dos	28 November 75 PM	Cape Perry	Barium Field Line Tracing
Buaro	Buaro	7 June 76 PM	Hawaii	Barium Field Line Tracing
Stress	Stress - Betty	26 February 77 AM	Florida	Barium Thermite Release
Lagopedo	Lagopedo I	2 September 77 AM	Hawaii	Barium Field Line Tracing
	Lagopedo II	12 September 77 AM	Hawaii	Barium Field Line Tracing
Stress	Stress - Carolyn	2 March 77 AM	Florida	Barium Thermite Release
	Stress - Dianne	7 March 77 AM	Florida	Barium Thermite Release
	Stress - Esther	13 March 77 AM	Florida	Barium Thermite Release
	Stress - Fern	14 March 77 AM	Florida	Barium Thermite Release
Avefria	Avefria I	8 May 78 AM	Nevada	Barium Field Line Tracing
	Avefria II	18 May 78 AM	Nevada	Barium Field Line Tracing
Camio	Camio	29 October 78 AM	Alaska	
Colimbo	Colimbo	22 February 79 AM	Hawaii	To Produce Barium from Baritol – No Good

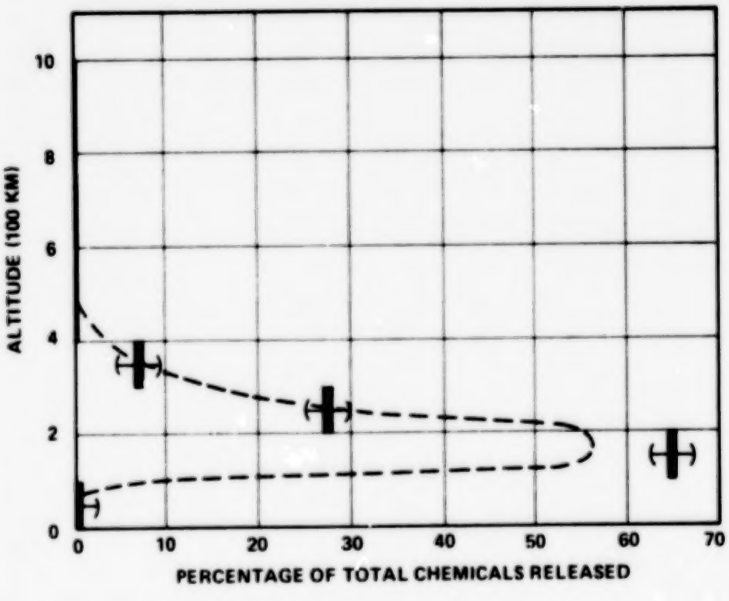
Table B-3
List of Ion Cloud Releases with Experimental Parameters (1968-1971)

Name	Date	Time	Latitude	Longitude	Altitude	Size
Apple	May 2, 1968	0917:16UT	16.650°N	66.793°W	196.0 km	12 kg
Birch	May 7, 1968	0902:50UT	18.571°N	66.697°W	207.0 km	2.0 kg
Cherry	May 12, 1968	no release				
Dogwood	May 13, 1968	0910:44UT	18.750°N	66.971°W	191.0 km	48 kg
Elm	March 6, 1969	0432:02UT	65.48°N	147.13°W	140/170 km	12/12 kg
		0431:47UT	65.16°N	147.00°W		
Fir	March 15, 1969	0508:15UT	55.34°N	147.52°W	165.0 km	48 kg
Gum	March 19, 1969	0519:15UT	65.34°N	147.34°W	168.0 km	48 kg
Hemlock	March 20, 1969	0539:11UT	65.40°N	147.21°W	175.8 km	96 kg
Ironwood	March 11, 1969	1409:41UT	65.40°N	147.18°W	128/168 km	12/12 kg
		1410:47UT	65.43°N	147.03°W		
Juniper	March 5, 1969	0431:48UT	65.39°N	147.35°W	140/170 km	6/2.4 kg
		0432:24UT	65.53°N	146.97°W		
Kumquat	September 5, 1969	0157:36UT	32.850°N	105.833°W	191.0 km	16 kg
Lime	September 6, 1969	0155:36UT	32.850°N	106.550°W	201.5 km	16 kg
Mulberry	September 13, 1969	0145:34UT	32.783°N	106.533°W	195.8 km	16 kg
Nutmeg	January 16, 1971	2334:40UT	29.903°N	86.422°W	150.9 km	48 kg
Olive	January 29, 1971	2353:57UT	29.790°N	86.690°W	193.4/185 km	320/16 kg
		2353:59UT	29.816°N	86.691°W		
Plum	January 20, 1971	2347:05UT	29.875°N	86.349°W	185.7 km	48 kg
Quince	February 2, 1971	1634:06UT	29.8962°N	86.3363°W	180.7 km	48 kg
Redwood	January 26, 1971	2332:09UT	39.703°N	86.634°W	255.6 km	48 kg
Spruce	February 1, 1971	2352.04UT	29.740°N	86.575°W	187.3 km	48 kg
Tango	October 21, 1971	2313:42UT			201.0 km	2 kg



Source: "Chemical Releases from Space Shuttle Payloads," Thiokol Wasatch Division May 1975, Ogden, Utah, NAS 5-24052, p. 3-3.

Figure B-1. Launch Locations for Chemical Release Payloads



Source: "Chemical Releases from Space Shuttle Payloads," Thiokol Wasatch Division May 1975, Ogden, Utah, NAS 5-24052, p. 3-3.

Figure B-2. Approximate Altitude Distribution for Chemical Releases

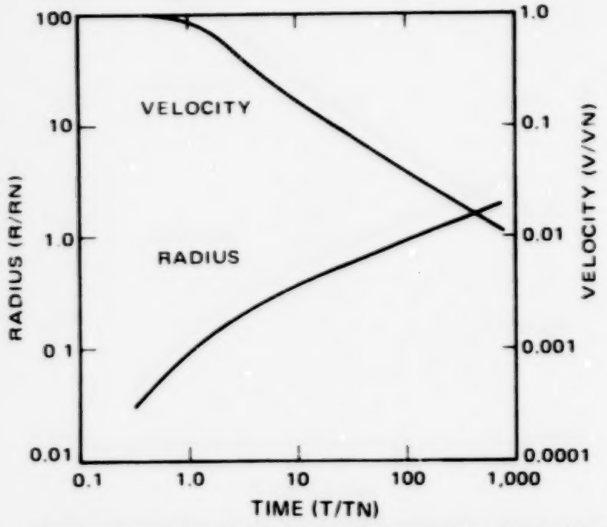
THEORY OF INITIAL DISPERSION AND SPREAD

A brief summary of the initial dispersion and expansion is given below. Most past experiments involved releases in the lower regions of the atmosphere from vehicles with velocities substantially lower than the orbital velocities which will apply for releases from the shuttle. At very high altitudes and low density, the velocity of the vehicle imparted to the released chemical cloud must be considered in experiment planning (Source 2.7). For releases from high-velocity vehicles at lower altitudes, the ambient atmosphere will stop the vapor or gaseous cloud relatively quickly by collisions (Source 2.5). In either altitude regime liquid and solid particulate material will tend to continue in orbit. These high-velocity effects have to be considered for the Space Shuttle program. The expansion of a gas of vapor cloud in near-vacuum has been treated in several studies (Source 2.8) and the theoretical "snowplow" model provides a generally accepted approach to estimating early-time cloud expansion characteristics. A two-phase expansion is utilized. The first phase is characterized by a decreasing velocity as the mass of ambient gas entrained becomes significant relative to the released mass. At about the time these masses are equal, the initial expansion ends and diffusion processes dominate.

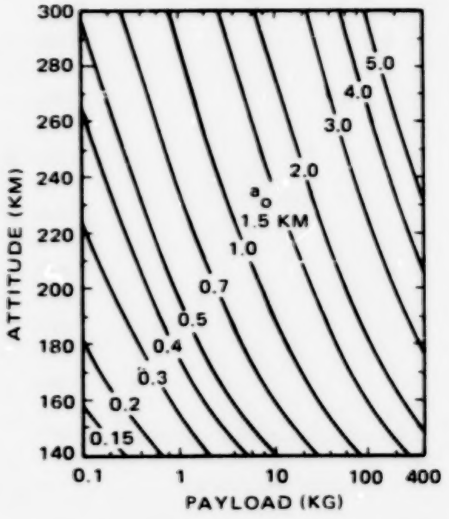
Atmospheric releases have shown general agreement with this theory. Knowing the altitude, plus the mass and temperature of vapor or gas released in an experiment, allows estimation of the size of the expanded cloud at early times.

Expansion due to diffusion, movement due to gravitational fields and winds, and electric field and magnetic field influences determine the time-history of chemical cloud development after its initial expansion. The cloud dimensions may extend to the order of several kilometers for small, low-altitude releases but may be, depending upon the definition, of the order of a 100 km or more for larger releases at collision-free altitudes. In Figure B-3 from Source 1.40 some illustrative graphs are given depicting in quantitative fashion the foregoing descriptive material.

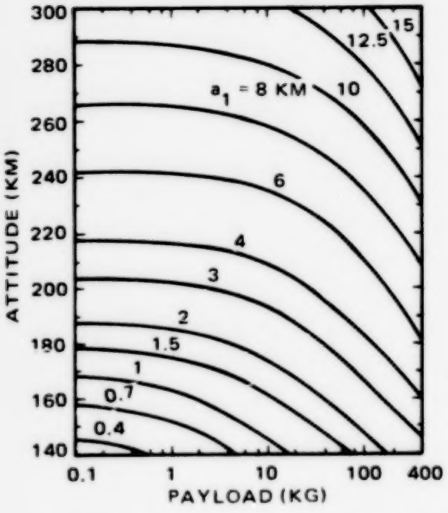
Recently two detailed studied of high-altitude releases from the rocket or Space Shuttle have been made. That of Linson and Baxter (Source 2.7) deals with the behavior of gas clouds provided by releases possessing orbital velocity in either a point release or venting mode in an intermediate altitude regime in the transition from self-continuum to diffusive flow. Included are calculations of the time dependence of the radius of the cloud, average internal energy, translational velocity and distance traveled. Figure B-4 is a typical calculation. Bernhardt (Source 2.8) has extended the range of calculations to a non-uniform atmosphere. See Figure B-5 as a typical calculation. From these developments the releases from the Space Shuttle may be effectively calculated for experimental assessment purposes.



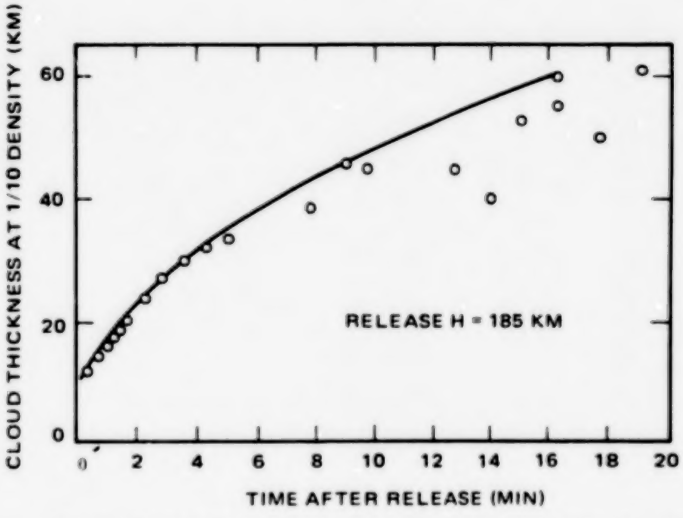
Stuart's Snowplow Model for Initial Expansion. Normalized radius RN =1 when mass of air swept up = mass of released gas. Normalized velocity VN = 1 for released gas at release temperature. Normalized time = RN/VN when equal mass would be swept up if velocity remained constant.



Equal Mass Radius for Barium as a Function of Altitude and Payload (Assumes Vapor Mass = 0.2 P) (After L. Linson)



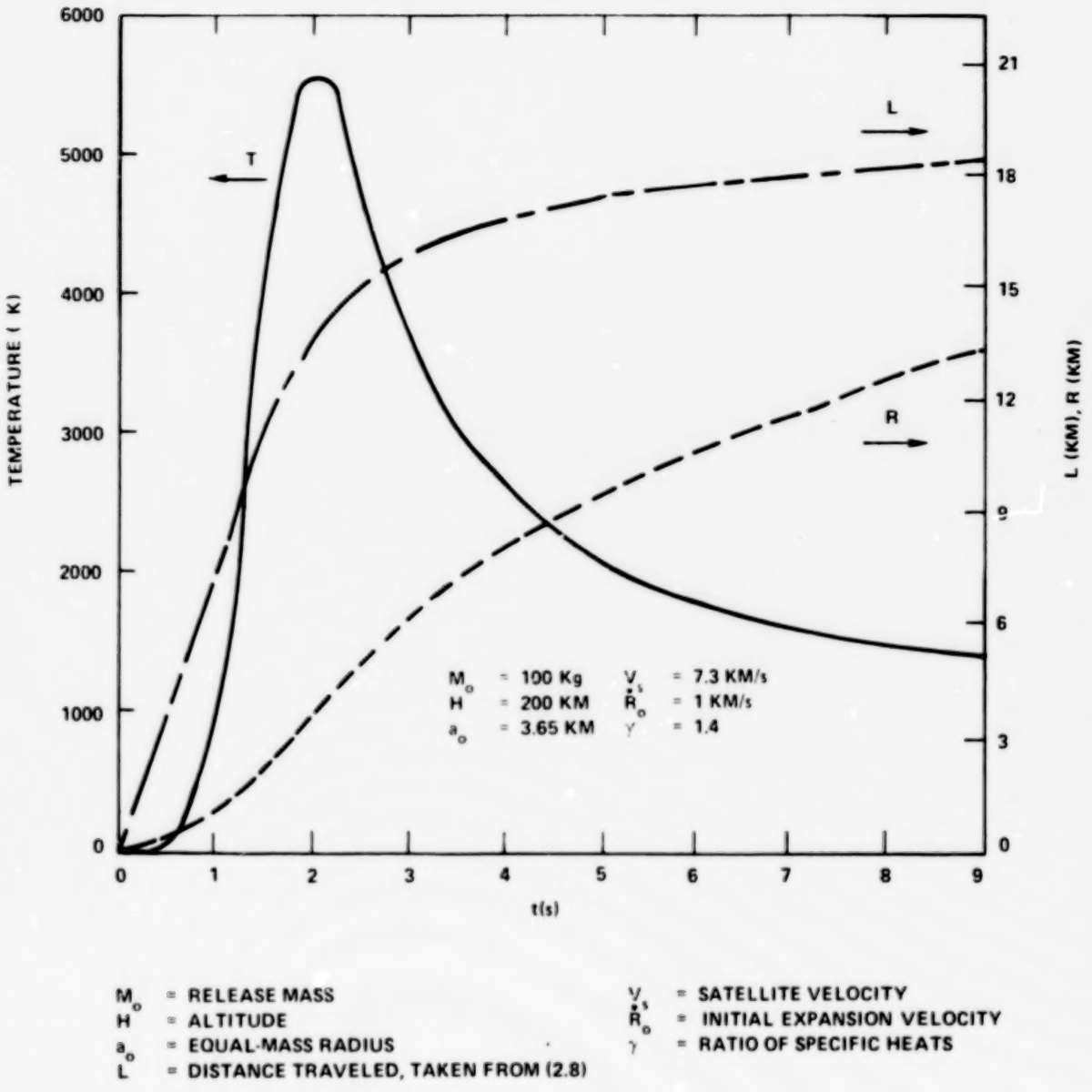
Scale Size of Ba Ion Cloud Transverse to Magnetic Field as a Function of Altitude and Payload $t \leq 1$ minute (Assumes Vapor Mass = 0.2P) (After L. Linson)



Extent of Large Ba Ion Cloud Along Magnetic Field Line at Late Time (After L. Linson and G. Meltz)

Source: Linson, L.M. and D.C. Baxter, "Gas Release and Conductivity Mortification Studies," Science Applications Inc., Final Report. NAS-5-24127.

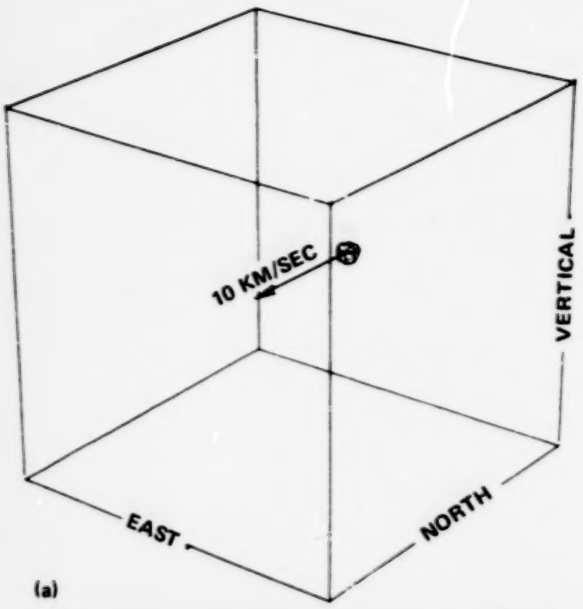
Figure B-3. Some Representative Calculations for Initial Cloud Growth



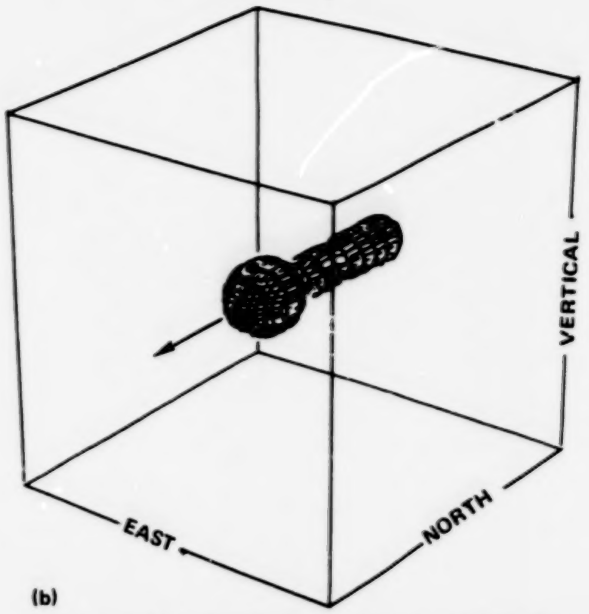
M_o = RELEASE MASS
H = ALTITUDE
a_o = EQUAL-MASS RADIUS
L = DISTANCE TRAVELED, TAKEN FROM (2.8)

V_s = SATELLITE VELOCITY
$\dot{R}_o$ = INITIAL EXPANSION VELOCITY
γ = RATIO OF SPECIFIC HEATS

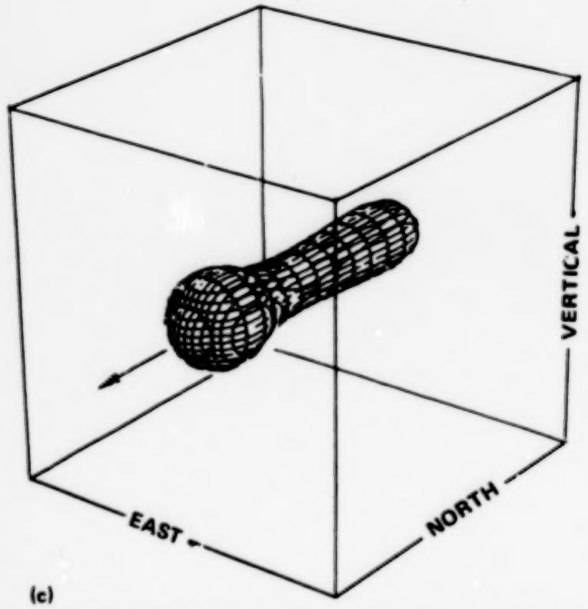
Figure B-4. Temperature, Radius, and Distance Traveled vs. Time for a 100kg Gas Release at Orbital Velocity and at 200km Altitude



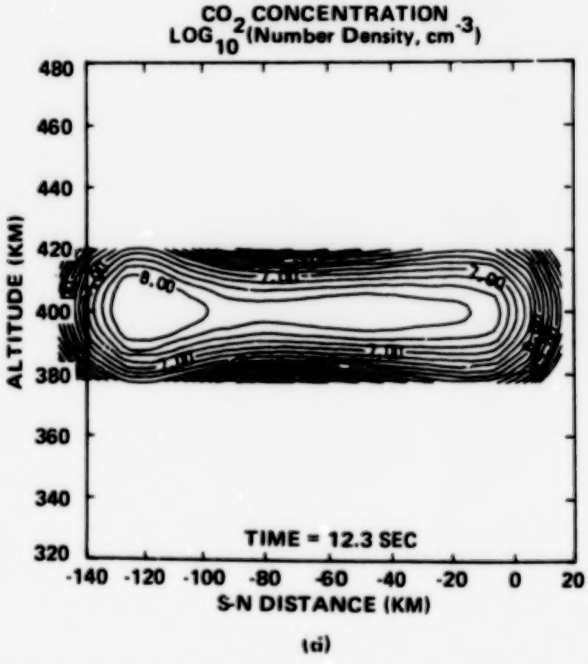
160.0 km CUBE CENTERED AT 400.0 km ALTITUDE
TIME AFTER RELEASE: 2.5 sec
CO_2 CONCENTRATION AT SURFACE: 9.2[8] cm^{-3}



160.0 km CUBE CENTERED AT 400.0 km ALTITUDE
TIME AFTER RELEASE: 8.8 sec
CO_2 CONCENTRATION AT SURFACE: 2.1[7] cm^{-3}



160.0 km CUBE CENTERED AT 400.0 km ALTITUDE
TIME AFTER RELEASE: 12.3 sec
CO_2 CONCENTRATION AT SURFACE: 9.3[6] cm^{-3}



Source: Bernhardt, P.A., "High Altitude Gas Releases-Transitions from Collisionless to Diffusive Flow in a Nonuniform Atmosphere," EOS, Transactions of the American Geophysical Union, vol. 59 (1978), p. 1162; also *Journal of Geophysical Research,* vol. 84 (August 1, 1978), p. 4341.

Figure B-5. Formation of a Cometlike Tail on a High-Velocity Point Release, Moving Horizontally. Scattering of Injected Molecules Cause the Elongation of the Originally Spherical Vapor Cloud.

APPENDIX C

SOME DATA ON THE GEOPHYSICAL ENVIRONMENT

In this appendix a limited collection of geophysical data and information restricted to and relevant to the CRM assessments is presented. For additional data and material the following is recommended to the reader:

1. *The Upper Atmosphere and Magnetosphere*, National Academy of Sciences, 1977.

2. *Physics of Magnetic Substorms*, S. Akasofu, D. Reidel Publishing Company, 1977.

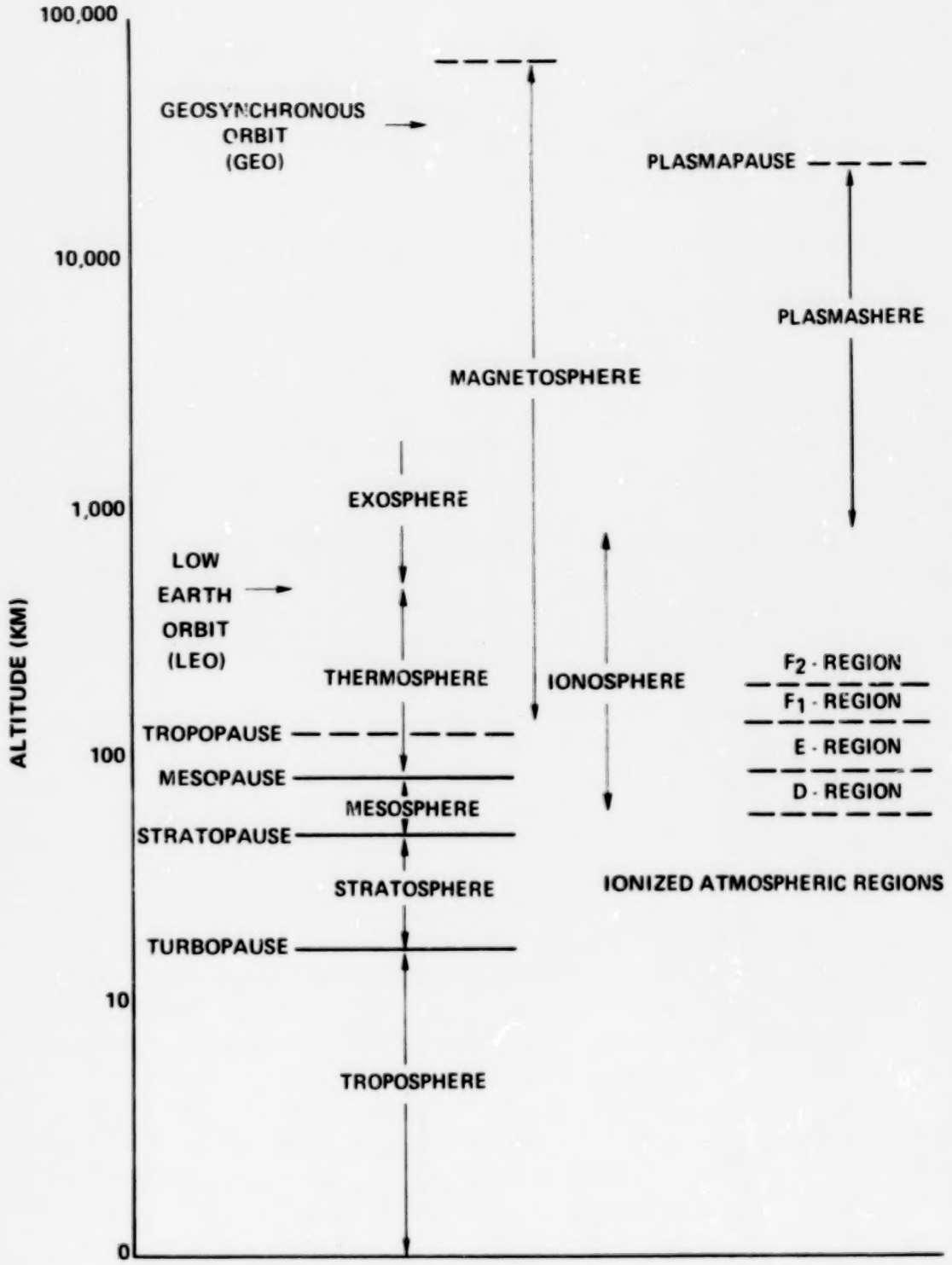
3. *Physics of Planetary Ionosphere*, S. J. Bauer, Springer-Verlag, 1973.

This appendix is divided into three Parts: Part 1–Basic Geophysical Data contained in Figures C-1 to C-4; Part 2–A Brief Discussion of the Ionosphere; and Part 3–Some Data on Micrometeorites.

SUMMARY OF GENERAL IONOSPHERIC PROPERTIES AND RADIO PROPAGATION (FROM SOURCE 2.27)

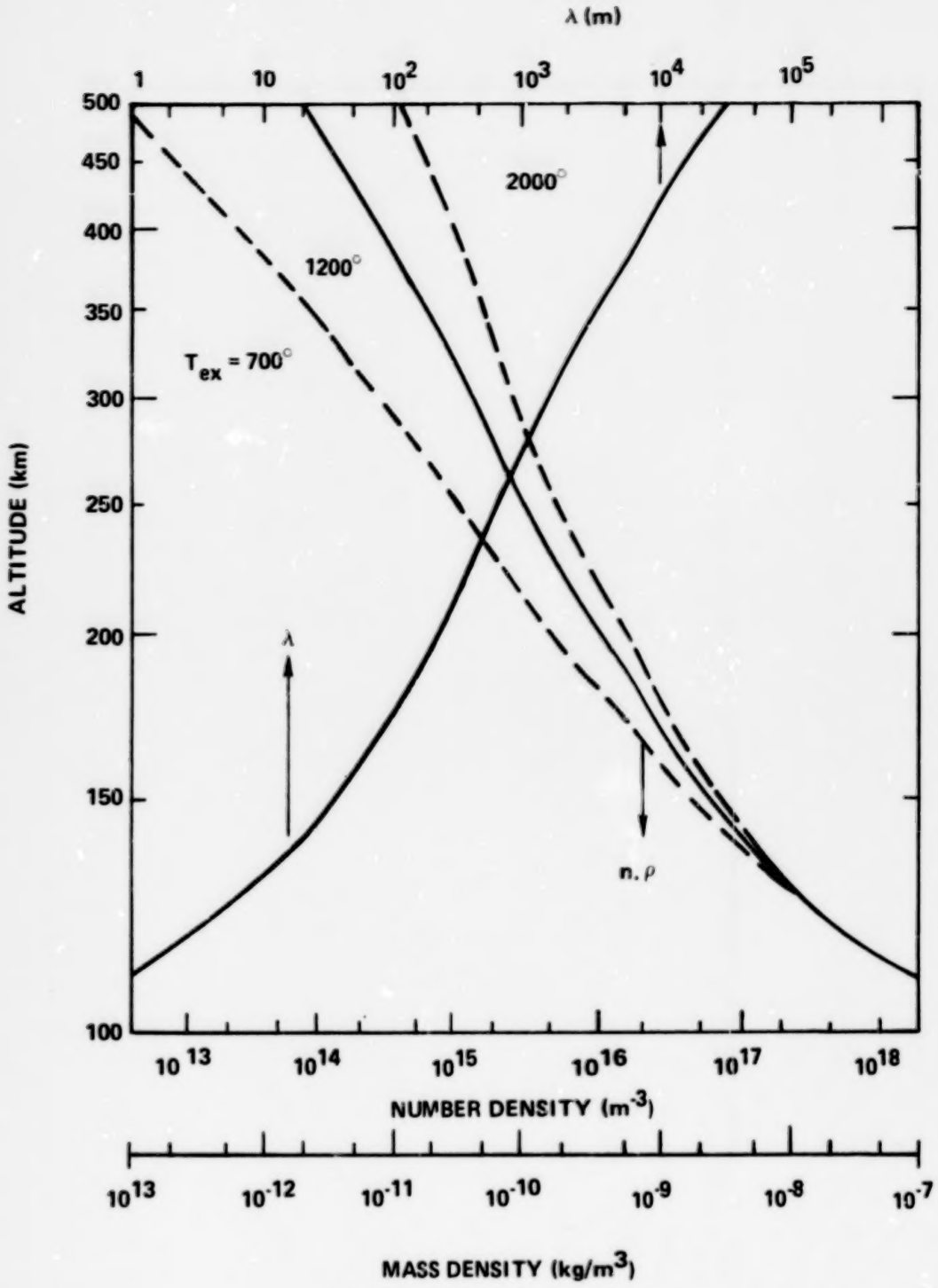
The ionosphere is that region of the earth's upper atmosphere where the constituent gases are slightly (up to 1 percent) ionized, mainly by solar radiation. The ionosphere, then, can be identified as a plasma. It is macroscopically an electrically neutral region with equal numbers of positive and negative particles, but the negatively charged electrons, being much less massive than the positive ions, are the particles that interact most strongly with radio waves. One aspect of this interaction has been exploited for many years to provide relatively inexpensive long-distance HF communications, by virtue of the ionospheric bending or refraction of radio waves back toward the earth at appropriate frequencies.

Ionization, in amounts large enough to have significant effects on radio waves, begins in the D-region at an altitude of about 60 km, and the density of ionized particles tend to increase with height through the D- and E-regions as shown in Figure C-5. Above these regions is the F-region, where the rare atmosphere contains a total of about 10^9 particles/cm^3. Most of the particles are neutral gases, consisting largely of O_2, O, N_2, and He. However, some of the particles are ionized, and at a height of about 300 km, peak electron and ion densities in the neighborhood of 10^6 particles/cm^3 occur. Above and below that altitude, fewer ionized particles are created, and their density-height profile, as in Figure C-5, is approximately the shape of a parabola. In addition to particle density, another characterization of the various constituents in the ionospheric plasma is their temperature or energy equivalent, derived from the kinetic theory of gases. Typical daytime values of electron, ion, and neutral temperatures near 300 km altitude at Boulder, Colorado are, respectively, 2000 K, 1000 K, and 950 K (0.175, 0.088, and 0.083 eV). Particle temperature is a function of altitude, and a representative profile is also shown in Figure C-5. The ionosphere is a very dynamic medium and ionization density-height and temperature-height profiles and other characteristics vary diurnally, seasonally, with solar activity, and with latitude and longitude.



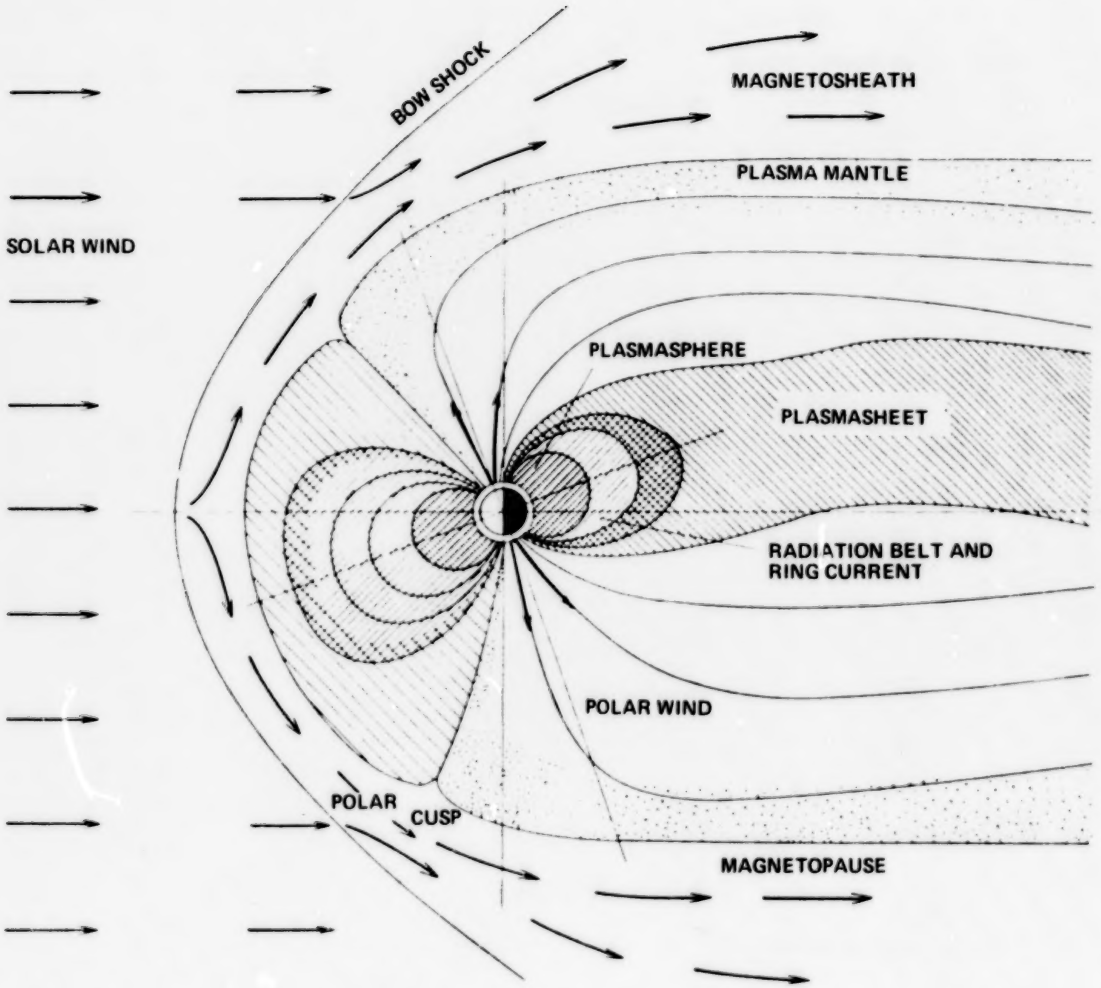
Source: NASA, "Environmental Impact Statement Concerning Activities of the National Aeronautics and Space Administration at Wallops Island, Virginia."

Figure C-1. Regions of the Atmosphere



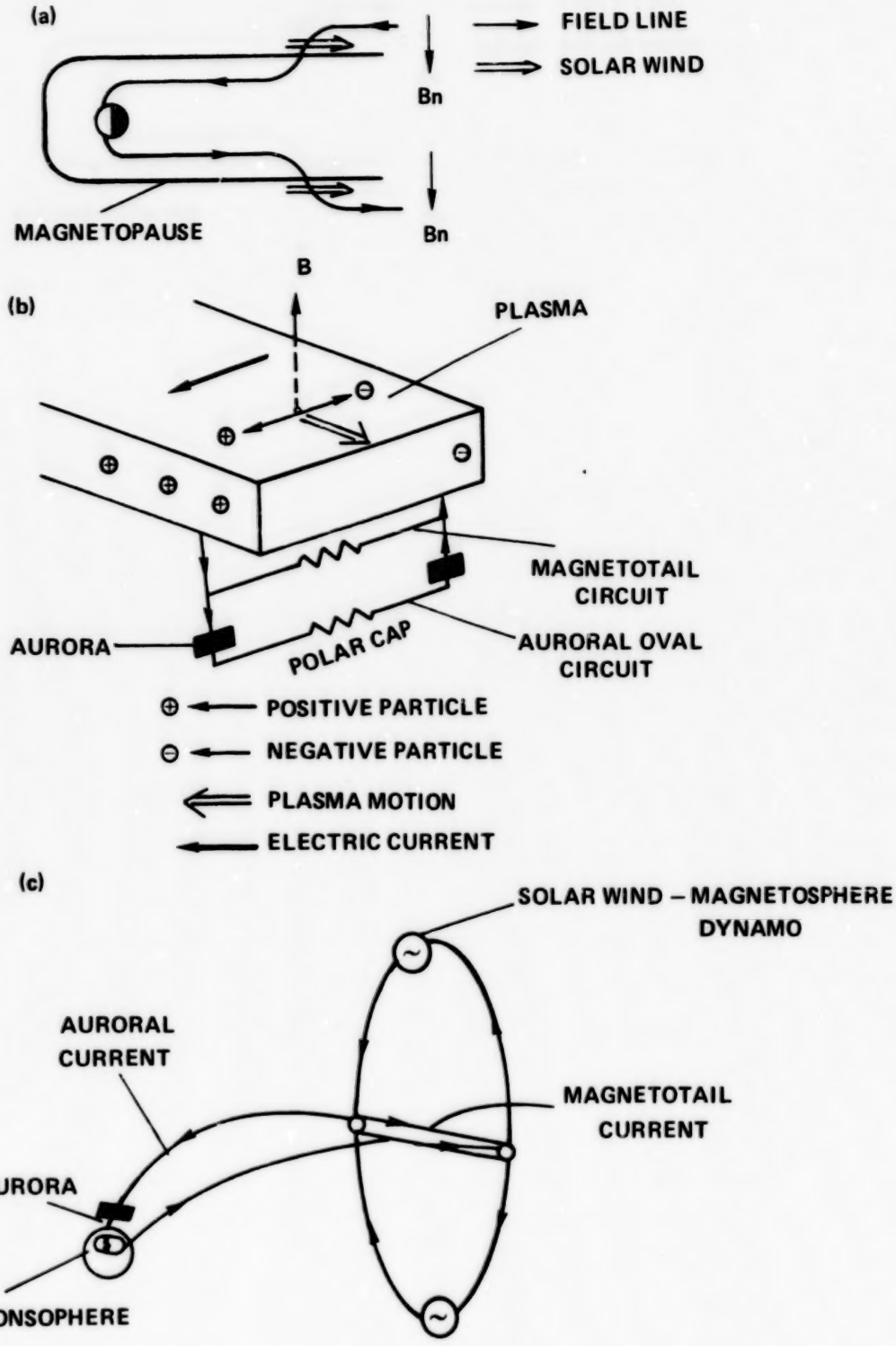
Source: Linson, L.M. and D.C. Baxter, "Gas Release and Conductivity Mortification Studies," Science Applications Inc., La Jolla, Calif., Final Report, SAI 02379-713LJ, LAPS-S1, May 1979, NAS 5-24127.

Figure C-2. Number Density, n, Mass Density, P_a, and Mean-Free-Path, λ, as a Function of Altitude Based on the CIRA 1972 Model Atmosphere. (Note the logarithmic altitude scale. The solid curves correspond to an exospheric temperature $T_{ex} = 1200°$; the dashed curves correspond to $T_{ex} = 700°$ and $2000°$.)



Source: NASA, "Chemical Release Module–A Multi-User Facility for Shuttle Spacelab," Goddard Space Flight Center, May 1979.

Figure C-3. Geophysical Regimes



Source: Akasofu, S., *"Physics of Magnetospheric Substorms,"* D. Reidel Publishing Company, 1977, p. 619.

Figure C-4. Processes Associated with the Solar Wind-Magnetosphere Dynamo. The location where the dynamo action takes place is schematically shown in (a). The basic processes associated with the dynamo and the connected circuits are shown in (b) and (c).

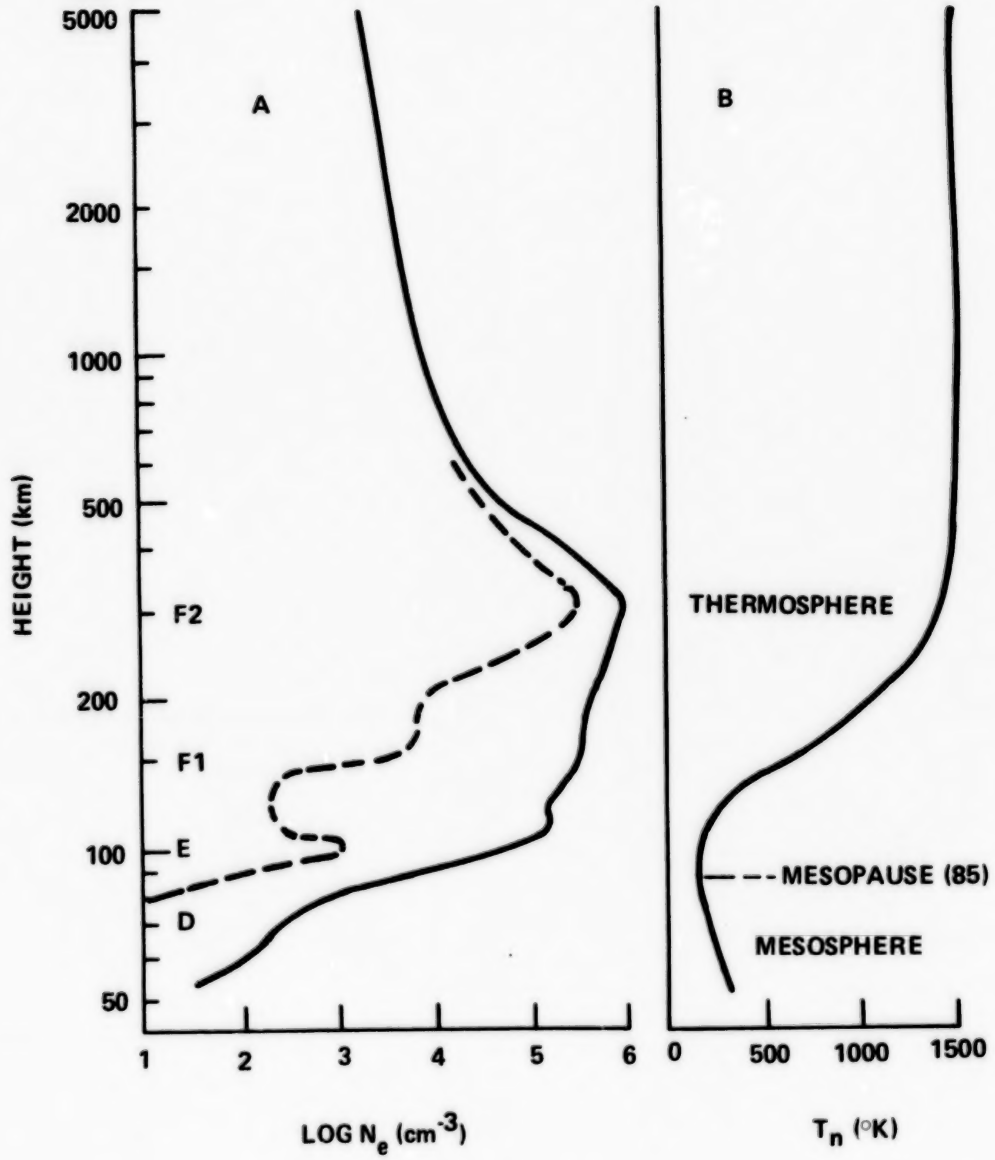
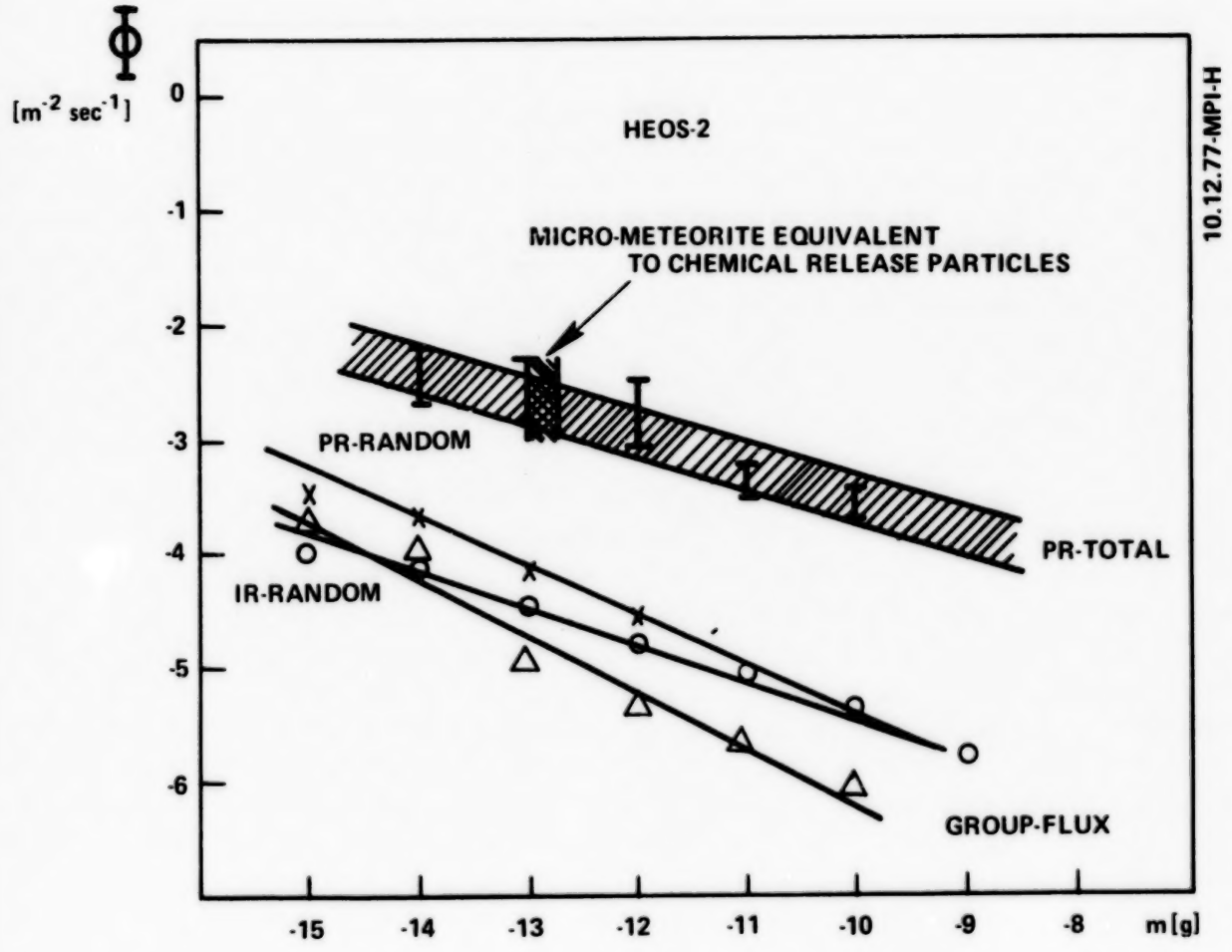


Figure C-5. Representative Electron Density Profile for Daytime (Solid Line) and Nighttime (Dashed Line) Ionosphere, Showing Strata Known as *D*, *E*, F_1, and F_2 layers (A). Representative Daytime Ionospheric Temperature Profile (B).



Source: Fechtig, H., E. Gruen, and G. Manfil, "Micrometeoroids within Ten Earth Radii," *Planetary and Space Science*, Vol. 27, pp. 511-531, 1979.

Figure C-6. Interplanetary Dust Fluxes below 60.000 km (PR region) IR-random: Sporadic dust flux of deep space a 1 AU. PR-random: sporadic dust flux in PR-region. Group-flux: Fluxes of lunar ejecta. PR-total: Total flux in PR-region. PR is perigree region near 10 earth radii.

With the preceding brief descriptions of the ionosphere and plasmas in mind, we turn now to consideration of the consequences of a radio wave traveling into a plasma region.

A quantity of fundamental importance in considering radio wave propagation in a plasma, is the plasma frequency. The plasma frequency f_N is given by

$$f_N^2 = \frac{Ne^2}{4n^2 e_o m} \tag{1}$$

where N, e, and m are, respectively, the number density, charge, and mass of the particles, and e_o is the permitivity of free space. Ion plasma frequencies are very low in comparison with electron plasma frequencies because of the high mass of the ion particles, which are primarily O^+ ions in the F-region. The plasma frequency is the characteristic oscillation rate for electrostatic disturbances in a plasma, and electrons and ions naturally oscillate back and forth weakly at their respective plasma frequencies. For the discussion that follows, the electron plasma frequency is of greater importance and when the term "plasma frequency" is used, it pertains to electrons. As a reference point, we note that an electron density of 10^6 electrons/cm^3 corresponds to a plasma frequency of 9 MHz. This is representative of maximum plasma frequencies in the ionosphere.

Under the influence of a passing electromagnetic wave, an oscillatory motion at the frequency of the wave is imparted to ions and electrons in a plasma; consequently, some energy from the wave is absorbed, because of collisions, and some is reradiated. As far as the effect on the electromagnetic wave is concerned, the plasma appears as an imperfect dielectric, having an effective dielectric constant and an effective conductivity that differ from those of free space. The effective dielectric constant is reduced below that of free space, while the conductivity is increased. Both the dielectric constant and conductivity depend upon the local plasma frequency and the collision frequencies between particles, principally between electrons and ions. They are also strongly dependent upon the frequency of the incident radio wave so that the ionosphere is a dispersive medium, but different from what one is used to in optics. The region is in the realm of anomalous dispersion; the ionosphere is a "rarer" medium for radio waves. One consequence of the dependence of the dielectric constant upon plasma frequency is that as a radio wave enters the ionosphere from below, it moves from a region where the refractive index is united into one where the index decreases as the wave encounters increasing electron density. The index of refraction for a radio wave having a frequency equal to the local plasma frequency is zero. At that point, the group velocity of the wave also becomes zero and the wave is reflected. The maximum ionospheric plasma frequency at a given time is called the "critical" or "pentration" frequency of the F layer. It is the lowest frequency radio wave that would pass through the ionosphere, and typically it ranges from about 3 to 10 MHz.

INPUT OF MICROMETEORITES INTO THE EARTH'S UPPER ATMOSPHERE

Mass Input of Barium and Other Species

The annual addition of cosmic dust in the earth's upper atmosphere has been estimated as between 1.6×10^7 kg/year (Hughes, 1975) and 5×10^7 kg/year (Cosby and Lyle, 1965). Consequently, the

proposed CRM annual mass injection rate of 10^3 kg is approximately 10^{-4} times the meteoritic rate, although for some specific species such as Ba or Li, it can be much greater. For Ba with a meteoritic abundance of 3×10^{-6} (Mason, 1971), the meteoritic injection amounts to 50 to 200 kg Ba/year.

Enhancement of Ambient Barium due to CRM Releases[1]

Let us assume a maximum plausible CRM input into the upper atmosphere of 1000 kg Ba/year. This larger than the presumed meteoritic input of 3×10^{-6} (Mason, 1971) times $(1.6\text{-}5) \times 10^7$ kg/year (see above), or 50 to 200 kg Ba/year.

Of concern to the biosphere would be the resultant enhancement in the atmosphere's planetary boundary layer (and spread uniformly over a depth of 1 km in the globe, this would give an enhancement of 2×10^{-7} $\mu g/m^3$-year) or in the upper ocean (spread uniformly over a depth of 50 m in the global ocean, this would give an enhancement of 6×10^{-17} gm/gm seawater-year, or 6×10^{-5} $\mu g/m^3$-year).

A mean turnover time in the atmospheric boundary layer is 1 to 10 days (see, e.g. Reiter and Bauer, 1975) and in the upper ocean, 100 to 1000 years (Broecker, 1963). Thus, with measured air values of .006 $\mu g/m^3$ in the atmosphere and 10^{-5} gm/gm seawater[2] (see also Appendix F, for references and ranges), fractional enhancements of barium are of order 3×10^{-7} in the atmosphere, or 2×10^{-9} in the ocean. These values may fluctuate by 1 to 2 orders of magnitude; note, however, that some of the added material in the atmosphere will tend to be $BaSO_4$ which is insoluble, inert, and nontoxic.

Evidently most of the barium in the biosphere must be due to terrestrial sources such as wind-blown dust, sea spray, and the combustion of coal and other fossil fuels (see Appendix F).

Meteoritic Flux in Space

The flux of micro-meteorites in space (Source 2.21) is based on the latest experimental measurements from the HEOS micro-meteorite measurements of H. Fechtig and associates during 1972 to 1974. See Figure C-6.

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[1]Bauer, E., "Report of the Review Panel on Environmental Assessment of the CRM Program," 1980 (Part I of this technical paper).

[2]Goldberg, E. D., "The Oceans as a Chemical System," Ch. 1 in M. N. Hill, Ed., *The Sea – Vol. 2*, Wiley-Interscience, 1963.

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1. Broecker, W. S., "Radioisotopes and Oceanic Mixing," Technical Progress Report No. C00-3180-2, Lamont-Doherty Geological Observatory, Palisades, N.Y., May 1974.

2. Cosby, W. A. and R. G. Lyle, "The Meteoroid Environment and Its Effect on Materials and Equipment," NASA, SP-78, 1965.

3. Hughes, D. W., "Cosmic Dust Influx to the Earth," Space Research, *15*, 1975, p. 531.

4. Mason, B., "Handbook of Elemental Abundances in Meteorites," Gordon and Breach, Science Publishers Inc., 1971, p. 530.

5. Reiter, E. R. and E. Bauer, "Residence Times of Atmospheric Pollutants," The National Stratosphere of 1974, CIAP Monograph, Department of Transportation Report DOT-TST-75-51, Institute for Defense Analysis, Science and Technology Division, Final Report, September 1975, pp. 2-134.

APPENDIX D

SUPPORTING CALCULATIONS ON THE EFFECT OF CHEMICAL RELEASE EXPERIMENTS ON SPACECRAFT

The function of this appendix is to provide some quantitative estimates for the degree of probability or improbability that a chemical release experiment might affect spacecraft or spacecraft sensors. The appendix is divided into two parts. In Section 1 (excerpt from memo J. J. Scialdone) an exemplar calculation is utilized that has been carried out for a co-orbital satellite 50 km away from a 32 kg barium release which was an initial planning condition for the Cameo experiment. The calculation is for a simple isotropic expansion and finds no significant effects by five order of magnitude (10^5) to form a monolayer because of the gases released impinging on the spacecraft. In Section 2, the isotropic model for particulate expansion is justified relative to the actual spreading along the orbit.

The effect of the particles released for the model adopted is the equivalent, in terms of micro-meteorite cratering, of an exposure in orbit of 3 hours to 1 day. It is noted that the time equivalent for a micro-meteorite mass flux is calculated in Section 1 but to get the equivalent cratering effect the masses for the two particle sizes quoted (4×10^{-9} and 2×10^{-6} g) must be converted to micro-meteorite masses of 2×10^{-13} g and 3×10^{-12} g. The frequency from Figure C-6 then gives the quoted equivalent time for micro-meteorite exposure of 3 hours and 1 day approximately. It is noted that an impact velocity of only 25 m/sec is, however, generally nondamaging as it is below the elastic limit. For a counter-rotating satellite, the situation is different since here the relative velocity can be approximately 14 to 16 km/sec and the equivalent micro-meteorite exposure is approximately 85 to 285 days. If all the particles impinging simply stick on the exposed surface, it can be seen that the surface coverage amounts to approximately 10^{-8} to 10^{-9} of the surface area which is not enough to affect a spacecraft or sensors.

The calculations further indicate that the contamination concentrations in orbit will be less than levels normally present in carefully controlled factory-to-launchpad environments.

Because of the direct relationship to mass, for a 10^3 kg release at a 50 km distance the possible mono-layer fraction increases by a factor of 30 and becomes 3×10^{-4} and the equivalent micro-meteorite exposure time for cratering becomes of the order of days to weeks relative to the 32 kg release for the co-orbital case.

1. Exemplar Calculation (For Cameo Experiment) On Chemical Release Effect on Spacecraft Sensors (from memo by J.J. Scialdone, 3/20/78 to NASA Review Team)

DATA

Mixture release: 32 kg

Consist of,

Barium vapor (10 percent) ..... 3.2 kg
Velocity approximately 1.0 km/s

Particulates:

1. $\leqslant 20 \times 10^{-4}$ cm dia particles (32 percent)..... 10.24 kg
   11×10^{-4} cm dia avg. particles
   4×10^{-9} g particles
   150 m/s speed particles

2. $\geqslant 20 \times 10^{-4}$ cm dia particles (58 percent)..... 18.56 kg
   80×10^{-4} cm dia avg. particles
   1.6×10^{-6} g avg. particles
   25 m/s speed particles

From U.S. Standard Atmosphere,

- Density @ 900 km alt. (He, 0) 7.87×10^{5} cm^{-3}
- Mean Free Path 2.1×10^{6} m
- Pressure 8.15×10^{-11} torr

From NASA TM78119, Rev. 1977, "Space and Planet Environment Criteria" document (Marshall),

- Meteoroid Environment (p. 233) Avg. Annual Meteor. Flux Model for particle meteorite $10^{-12} \leqslant m \leqslant 10^{-6}$ g
  $\log N_T = -14.339 - 1.584 \log m - .063(\log m)^2$
  hence: $m = 4.10^{-9}$ g $N_T = 3.31 \times 10^{-6}$ $P/m^2/s = 2.85 \times 10^{-5}$ $P/cm^2/day$
  $m = 1.6 \times 10^{-9}$ $N_T = 5.31 \times 10^{-8}$ $P/m^2/s = 4.58 \times 10^{-7}$ $P/cm^2/day$

  Meteorites Avg. V = 20 km/s

From Standards for Clean Rooms, NHB 5340.2 (NASA STD for Clean Rooms), p. 5.1.1,

Class 10000 (diameter)

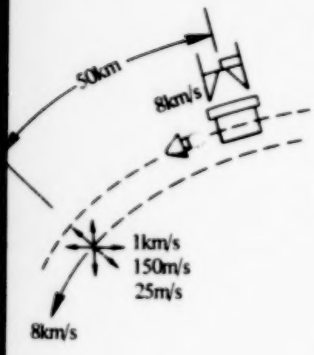
11×10^{-4} cm particle	$< 3.5 \times 10^{-1}$ part/liter (10 ft^{-3})
80×10^{-4} cm particle	$< 3.5 \times 10^{-3}$ part/liter (.2p/ft^3)

Class 100

11×10^{-4} cm	$< 3.5 \times 10^{-3}$ p/l
80×10^{-4} cm	$< 3.5 \times 10^{-5}$ p/l

CALCULATION

Assumptions The spacecraft is 50 km from the vapor and particulate release.



Vapor and dust move out radially and uniformly from the point of release.

The expansion is "free," there is no collision with ambient atoms.

The spacecraft and Cameo are moving at the same velocity

$$V \approx 8 \text{ km/s}$$

Vapor is approaching spacecraft at v = 1 km/s, particulates at 150 m/s and 25 m/s.

Flux Densities

1. For particles with an average mass = 4×10^{-9} g and an average diameter = 11×10^{-4} cm

Time to reach spacecraft:

$$t = \frac{50 \text{ km} \times 10^{-3} \text{ m/km}}{150 \text{ m/s}} = 333 \text{ sec} \sim 5.5 \text{ min}$$

The number of particles of this size released,

$$\frac{10.24 \text{ g} \times 10^{3}}{4 \times 10^{-9} \text{ g/part}} = 2.56 \times 10^{12} \text{ particle/release}$$

For conservation of mass within an expanding sphere, the flux density ρ(particle/cm^2) when these particles reach the spacecraft 50 km away, will be

$$\rho = \frac{\text{no. of particles}}{\text{surface of sphere}} = \frac{2.56 \times 10^{12}}{4\pi(50 \times 10^5)^2}$$

$$= 8.14 \times 10^{-3} \text{ part./ cm}^2$$

This flux density can be compared to the meteorite flux of the same size ($m = 4 \times 10^{-9}$ g) given by the equation in the references above.

$$\log N_T = -14.339 - 1.584 \log 4 \times 10^{-9} - .063(\log 4 \times 10^{-9})^2$$

$$= 5.4796 \qquad N_T = 3.31 \times 10^{-6} \text{ p/m}^2\text{/s} \left(\frac{10^{-4}\text{ m}^2}{\text{cm}^2}\right)$$

$$\frac{3.6 \times 10^3 \text{ s}}{\text{h}} \times \frac{24 \text{ h}}{\text{d}}$$

$$= 2.85 \times 10^{-5} \text{ p/cm}^2\text{/day}$$

Therefore, the flux density $\rho = 8.14 \times 10^{-3}$ p/cm^2 is equivalent to

$$\frac{8.14 \times 10^{-3} \text{ p/cm}^2}{2.85 \times 10^{-5} \text{ p/cm}^2\text{/day}} = 285 \text{ days}$$

of the meteorites of the same mass.

The energy of these particles will be $E = \left(\frac{150 \text{m/s}}{2 \times 10^4 \text{ m/s}}\right)^2 E_{meteors} = 5.6 \times 10^{-5}$ times the energy of a meteorite of the same mass.

2. For particles with an average mass = 1.6×10^{-6} g and an average diameter = 80×10^{-4} cm

Time to reach spacecraft,

$$\frac{50 \times 10^3 \text{m}}{25 \text{m/s}} \simeq 2000 \text{ s} \simeq 33 \text{ min.}$$

The number of particles released of this size

$$\frac{18.56 \times 10^3 \text{ g}}{1.6 \times 10^{-6} \text{ g/p}} = 1.16 \times 10^{10} \text{ particle.}$$

Again, for conservation of mass at 50 km, the flux density is

$$\rho = \frac{1.16 \times 10^{10}\,p}{4\pi(50 \times 10^5)^2} = 3.69 \times 10^{-5}\ p/cm^2.$$

The meteorites of the same size $m = 1.6 \times 10^{-6}$ g, using the recommended equation, have a flux

$$N_T = 5.31 \times 10^{-8}\,p/m^2/s = 4.59 \times 10^{-7}\,p/cm^2/day.$$

Therefore, the flux density $\rho = 3.69 \times 10^{-5}\,p/cm^2$ is equivalent to

$$\frac{3.69 \times 10^{-5}\,p/cm^2}{4.59 \times 10^{-7}\,p/cm^2/day} = 84.48 \text{ days}$$

of the meteorites of same mass.

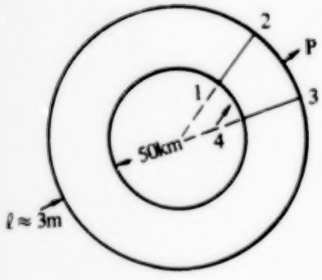
The energy of these particles will be

$$E = \left(\frac{25 m/s}{2 \times 10^4 m/s}\right)^2 E_{meteorite} = 1.56 \times 10^{-6}$$

times the energy of a meteorite of the same mass.

Particulate Densities

1.



Conservatively, apply to the stream tube 1,2,3,4, the conservation of mass, and assume the tube is about $\ell = 3m$ wide (approximately a s/c dimension).

$$\frac{\Delta m}{A\Delta t} = \frac{\dot{m}}{A} = nv \quad (p/cm^2 \cdot s)$$

$$n = \frac{\Delta m}{Av\Delta t} = \frac{\Delta m}{A\ell} \quad (p/cm^3)$$

Particle $m_a = 4.10^{-9}$ g, $\frac{\Delta m}{A} = \rho = 8.14 \times 10^{-3}\,p/cm^2$ (as per above).

$$n = \frac{8.14 \times 10^{-3}\,p/cm^2}{3 \times 10^2 cm} = 2.71 \times 10^{-5}\,p/cm^3$$

$$\text{Particle } m_a = 1.6 \times 10^{-6} \text{ g}, \frac{\Delta m}{A} = \rho = 3.69 \times 10^{-5} \text{ p/cm}^2$$

$$n = \frac{3.69 \times 10^{-5} \text{ p/cm}^2}{3 \times 10^{2} \text{ cm}} = 1.23 \times 10^{-7} \text{ p/cm}^3$$

2. Assume particles are uniformly distributed in the 50 km sphere

$m_a = 4 \times 10^{-9}$ g (11×10^{-4} cm dia); particle released = 2.56×10^{12}

$$n = \frac{2.56 \times 10^{12}}{4/3\,\pi R^3} = \frac{2.56 \times 10^{12} \text{ p/rel}}{5.23 \times 10^{20} \text{ cm}^3} = 4.9 \times 10^{-9} \text{ p/cm}^3$$

$m_a = 1.6 \times 10^{-6}$ g (80×10^{-4} cm dia); particle release = 1.16×10^{10}

$$n = \frac{1.16 \times 10^{10}}{5.23 \times 10^{20}} = 2.21 \times 10^{-11} \text{ p/cm}^3$$

These particle densities can be compared to Clean Room Std. for Class 100 and 10 000:

Class 10 000: $n < 3.5 \times 10^{-4}$ p/cm^3 for 11×10^{-4} μ dia and
$n < 3.5 \times 10^{-6}$ p/cm^3 for 80×10^{-4} μ dia

Class 100 : $n < 3.5 \times 10^{-6}$ p/cm^3 for 11×10^{-4} μ dia and
$n < 3.5 \times 10^{-8}$ p/cm^3 for 80×10^{-4} μ dia

BARIUM DEPOSIT AND ENVIRONMENT

Mass 3.2 kg/release

$m = 137.34$ kg/mole

dia mol or atom ~ 1.2 Å, $\sigma = \pi d^2 = 4.52 \times 10^{-16}$ cm^2

$$\text{atoms/monolayer} = \frac{1 \text{ cm}^2}{\sigma} = 2.21 \times 10^{15} \text{ atoms/cm}^2\text{/monolayer}$$

$$\text{Atoms ejected} = \frac{3.2 \text{ kg} \times 6.02 \times 10^{26} \text{ atom/kg mole}}{137.34 \text{ kg mole}} = 1.402 \times 10^{25}$$

Flux density at 50 km radius

$$\frac{\text{atoms ejected}}{4\pi(50 \times 10^5)^2} = \frac{1.402 \times 10^{25}}{314.16 \times 10^{12}} = 4.45 \times 10^{10} \text{ atoms/cm}^2$$

This density is 5 orders of magnitude less than required for a monolayer (2.2×10^{15} atoms/cm^2).

A monolayer could be obtained, assuming a very improbable sticking and accommodation coefficient of 1, if the spacecraft surface was at a radial distance of

$$R = \left(\frac{\text{atoms ejected}}{4\pi \cdot \rho \text{ monolayer}}\right)^{1/2} = \left(\frac{1.4 \times 10^{25}}{4\pi \cdot 2.21 \times 10^{15}}\right)^{1/2} = 224.5 \text{ m}$$

Density of Ba vapor

Assume: stream tube, density

$$n = \frac{\Delta m}{A \Delta t \cdot v} = \rho/1 = \frac{4.45 \times 10^{10}}{3 \times 10^2} = 1.48 \times 10^8 \text{ atoms/cm}^3$$

for a uniform dispersed density in 50 km sphere

$$n = \frac{\text{atoms eject}}{\text{volume}} = \frac{1.402 \times 10^{25}}{4/3\pi R^3} = \frac{1.4 \times 10^{25}}{5.23 \times 10^{20}} = 2.68 \times 10^4 \text{ cm}^{-3}$$

These densities compare to the ambient density of 7.86×10^5 cm^{-3} at 900 km altitude.

Table D-1
Cameo Summary of Calculations and Comparisons

Released Particles			Parameters Calculated at 50 km			Released Particle
Diam. (cm)	Mass (g)	Number	Time To S/C (sec.)	Flux Dens. (cm^{-2})	No Density ($liter^{-1}$)	Velocities (m/s)
11×10^{-4}	4×10^{-9}	2.56×10^{12}	333	8.14×10^{-3}	$2.7 \times 10^{-2} / 5 \times 10^{-6}$	150
80×10^{-4}	1.6×10^{-6}	1.16×10^{10}	2000	3.69×10^{-5}	$1.23 \times 10^{-4} / 2.2 \times 10^{-8}$	25

Clean Room Comparison

Particle Size (cm)	Clean Room Part. Dist. (part./liter)		Density @ 50 km (Part./Liter)
	Class 100	Class 10000	
11×10^{-4}	3.5×10^{-3}	3.5×10^{-1}	$2.7 \times 10^{-2} / 5 \times 10^{-6}$
80×10^{-4}	3.5×10^{-5}	3.5×10^{-3}	$1.23 \times 10^{-4} / 2.2 \times 10^{-8}$

Meteorites Energy Comparison

Released Particles		Meteorites		$\frac{\text{Energy Rel. Part.}}{\text{Energy Meteor.}} = \frac{E}{EM}$
Mass (g)	Velocity (m/s)	Mass (g)	Velocity m/s	
4×10^{-9}	150	4×10^{-9}	20×10^{3} avg	5.6×10^{-5}
1.6×10^{-6}	25	1.6×10^{-6}	20×10^{3} avg	1.56×10^{-6}

Barium Vapor Release

Ejected, 1.4×10^{25} atmos/molec.
Velocity, $\sim$ 1 km/s
Time to 50 km, $\sim$ 50 sec
Flux @ 50 km, 4.45×10^{10} cm^{-2}
Density @ 50 km, $1.4 \times 10^{8} / 2.7 \times 10^{4}$ c

Comparison:

Density @ 900 km, 7.86×10^{5} cm^{-3}
Monolayer Flux @ 225 m.
$\sim 2.21 \times 10^{15}$ atom/cm^2
Mean Speed of Particle $\sim$ 2 km/s
@ 900 km

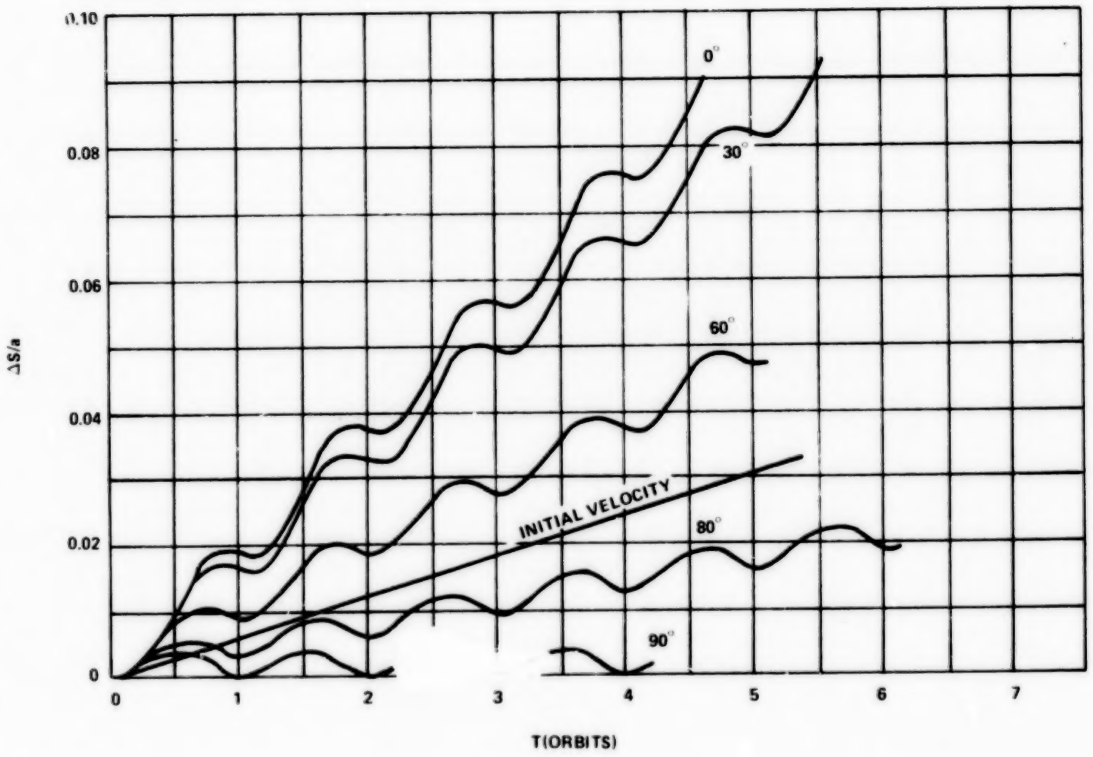
JUSTIFICATION OF THE ISOTROPIC EXPANSION MODEL FOR THE INITIAL PHASE

The effect of orbital dynamics and drag on small particles released from spacecraft or chemical releases in circular orbits has been calculated. It has been shown that such particles will become distributed along the orbital path and that the net separation rate, $\dot{\bar{S}}$, between the particle and the spacecraft (Source 2.22) is given by

$$\dot{\bar{S}} = \frac{3}{2} v_{\odot} \left| 2\frac{\delta v}{v_{\odot}} \cos\gamma + \left(\frac{\delta v}{v_{\odot}}\right)^2 - \frac{2C_D A\rho_a v_{\odot} t}{m} \right|$$

where $v_{\odot}$ is orbital velocity, δv is ejection velocity, γ is the angle of ejection relative to the orbital velocity vector, C_D is the drag coefficient, A/m is the area to mass ratio of the particle, ρ_a is the atmospheric density, and t is the time after ejection. Particles ejected randomly will be confined by orbital dynamics to a tube of cross-sectional area given approximately by $\pi\xi^2$ where $\xi = r_{\odot}\,\delta v\, v_{\odot}$ and $r_{\odot}$ is the orbit radius vector. An illustration of the separation rate is given in Figure D-1.

With regard to the confinement tube, for v = 8 km/sec, δv = 150/sec and r = 6878 km, ξ is 129 km. Consequently the assumption of isotropic expansion to 50 km is not inconsistent with a more complex picture. Moreover, as time increases, the particle density and flux decrease to levels less than that calculated in Section 1 because of the particle separation along the tube.



Source: Naumann, R.J., "Dynamics and Column Densities of Small Particles Ejected from Spacecraft," NASA TN D-7590, February 1974.

Figure D-1. Separation distance between particle and spacecraft. (Initially the particles leave at their given separation velocity, but after $\sim$ 0.1 orbit the orbital dynamics may either accelerate or retard the separation rate, depending on the ejection angle.) For $\delta v = 0.0005V$ and no drag.

APPENDIX E

CONSIDERATION OF LITHIUM CHANGES IN THE UPPER ATMOSPHERE

One of the chemical species in the upper atmosphere above 70 km, which will undoubtedly be affected by "large-scale" chemical releases, is lithium. As can be seen from Table E-1, the total amount of Li in the upper atmosphere above 70 km amounts to less than a kilogram in comparison with the multi-kilogram releases of lithium which are projected in the CRM program. Applying meteoritic input and lifetime considerations, the total atmospheric mass of lithium is of the order of 70 kg.

It is now well established that some high intensities reported for the Li line were caused by artificial injection of Li atoms into the atmosphere by bomb explosions, (source 2.24 and Refs. Table E-1). Several observations have shown that the Li intensity increases abruptly 2 to 3 days after a major nuclear bomb is exploded in the atmosphere. There is then a steady decrease of the intensity during the following month or more, indicating a slow fallout of the Li atoms. This artificial injection certainly makes it difficult to determine the atmospheric content of natural Li atoms.

Similar remarks appertain with a shorter time scale relative to the smaller and nonradioactive chemical releases of lithium. For example, following the Cameo release at 960 km in November 1978, lithium enhancements near 90 km were observed within less than one day using sensitive Lidar equipment but within two weeks the enhancement dropped below the background level of ambient lithium. In addition to recent Lidar techniques, the previously used twilight methods of observation are extraordinarily sensitive to resonant line trace elements, expecially the alkalis, Li, Na, K and the alkali-like ions Ca^+ and Ba^+. All but Ba^+ have been routinely observed in twilight studies at altitudes near 90 km in detectable amounts (alkalis are given in Table E-1). Hunten (source 2.24) states "enduring effect of Li injections have certainly been observed and may well have hidden any natural effect ever since the first observations in 1957." The only societal effect established for a lithium perturbation to our knowledge is the aeronomic scientific one in which the natural source is covered over. The lithium releases have a positive result in that in their long term perturbation, they undoubtedly will further increase our knowledge of lithium lifetime, sinks and sources, etc., and perhaps further discriminate between suggested natural sources such as meteors, the ocean, etc.

Table E-1

Mass of Upper Atmospheric Alkali Species for Comparisons with Chemical Release Module Payloads*

Species	Altitude Regime (km)	Max. Concentration (cm^{-3}) and ALT. (km)	Extimated Natural Flux ($cm^{-2}\ sec^{-1}$)	Total Particle per Column (cm^{-2})	Total Global Mass (kg)
1. Lithium	70-95	1.1 (80)	1.2×10^{1}	1.6×10^{6} (1)	.08
Total Lithium ($Li + Li + H_2O$)				2.3×10^{6} (2)	.12
2. Sodium*	85-95	1000 (91)	1.3×10^{4}	1.6×10^{9}	304
3. Potassium*	92-100	11 (95)	2.9×10^{2}	1.6×10^{7}	5.2

*Ratio of Li:Sodium:Potassium = 1:1000:10 Data synthesized from Refs. (1,2,3) below.

References

Mitra, V., "Deposition of Twilight Lithium by a High Altitude Thermonuclear Explosion," *Annales de Geophysique*, t. 30, fasc. 4, 1974, pp. 497-502.

Ibid., "Origin of Alkali Metals in the Earth's Atmosphere," fasc. 3, pp. 421-427.

Kvifte, G., *Atmospheric Emissions*, B. McCormack, G. A. Omholt, 1968.

APPENDIX F

TOXICITY OF BARIUM (ADAPTED FROM SOURCE 1.45)

There is little known about barium in the earth's atmosphere. Barium is the sixteenth most abundant element in the earth's crust, occurring at concentrations of 250 to 450 ppm as compared with 300 ppm for strontium and 36 000 ppm for calcium; seawater barium concentrations are 0.03 to 0.05 ppm.[1,2]

It is considered to be moderately toxic with a hazard potential directly related to the solubility of its compounds. Barium sulfate, a very insoluble compound, is considered to be nontoxic, and large quantities are routinely administered by mouth to patients undergoing X-rays of the GI tract. Two soluble compounds, barium carbonate and barium chloride, are considered to be quite toxic; the carbonate has been used as a rat poison. Soluble barium in the organism causes excitability of muscles and effects on the hematopoietic and nervous systems[2,3]. Inhalation of insoluble barium compounds, e.g. the sulfate, has produced "baritosis," a benign condition visible on X-ray examination of the lungs.

Sources for natural barium input into the upper atmosphere include meteors and micro-meteors. An estimate of the magnitude of these sources suggests an input of 50 to 200 kg/yr (Appendix C, Section 3). Barium enters the lower atmosphere by precipitation from higher altitudes, wind-blown dust, dehydration of seawater, combustion of fossil fuels, and many other processes. Trace quantities of barium are found in coal ash ranging from 0.05 to 0.8 percent for various continental American and Alaskan coals.[4]

The limit recommended for industrial exposure of 0.5 $\mu g/m^3$ in air, and the present OSHA standard, was based on experience at the Los Alamos Scientific Laboratory with the explosive constituent barium nitrate.[3] There is at present no ambient air quality standard for barium, but if there were, it could be expected to be much lower than 0.5 $\mu g/m^3$ – perhaps 5$\mu g/m^3$. Few studies have been made of ambient levels of barium in the atmosphere; it is not one of the elements presently measured by the various air sampling networks. A recent study, however, reported concentrations of 0.08 $\mu g/m^3$ in Denver and 0.09 $\mu g/m^3$ in St. Louis.[5] A 1956 study of two years' data collected by the U.S. Public Health Service Air Sampling Network which measured barium showed a median concentration of 0.006 $\mu g/m^3$ but included individual samples ranging up to 1.5 $\mu g/m^3$. This study included 754 samples from 20 cities and suburban sites.[6] While the strontium content of food has been studied extensively, there is only one known report of a barium measurement – an average of 0.35 ppm in a hospital diet.[2]

Both the absolute and relative enhancements of barium from projected CRM releases are many orders of magnitude below levels that might be of concern because of health effect (See Appendix C).

FOOTNOTES TO APPENDIX F

1. *Handbook of Chemistry and Physics,* 50th Edition, Chemical Rubber Co., 1970, p. F-144.

2. H.A. Schroeder, I.H. Tipton, and A.P. Nason, "Trace Metals in Man: Strontium and Barium," *J. Chronic Dis. 25,* 491 (1972).

3. Documentation of the Threshold Limit Values, Amer. Conf. of Govt. Ind. Hygienists, p. 21 (1971).

4. "Air Pollution Aspects of Barium and Its Compounds," Litton Industries, Bethesda, Md., September, 1967.

5. R.E. Lee Jr., S.A. Goranson, R.F. Enrione, and G.B. Morgan, "National Air Surveillance Cascade Impactor Network II. Size Distribution Measurements of Trace Metal Components," *Env. Sci. and Tech. 6,* 1025 (1972).

6. E.C. Tabor and W.V. Warren, "Distribution of Certain Metals in the Atmosphere of Some American Cities," *Arch. Ind. Health 17,* 145 (1958).

APPENDIX G

THE IMPACT OF CHEMICAL RELEASE EXPERIMENTS ON OPTICAL ASTRONOMY

This appendix includes material which is relevant to, and is utilized in, the main text for the assessment of the impact of chemical release experiments on optical astronomy. Its substance is an evaluation for this program by K. Janes and M. Mendillo of the overall problem of the effects of an increase in sky brightness. As stated by them, it does not directly assess any chemical release program or the CRM program in particular, as is done in the main text. Its function is to set limits—in particular for the impact on optical astronomy of frequent or steady-state changes in night sky brightness.

Following this report is a table providing a brightness comparison between chemical release and night sky feature brightnesses.

THE IMPACT OF CHEMICAL RELEASE EXPERIMENTS ON OPTICAL ASTRONOMY

(K. Janes and M. Mendillo, Boston University, Department of Astronomy)

In recent years, optical astronomers have become increasingly concerned with "light pollution"—the high level of illumination of the night sky by cities. The reasons for this concern are two-fold: first, many of the most interesting astrophysical problems require observations of exceedingly distant and faint objects; and second, the amount of artificial illumination is growing rapidly. Several recent studies (Hoag et al., 1973; Walker, 1973, 1977) have shown that city lights are becoming troublesome at several of the major western observatories and that there are few, if any, sites in the U.S. with a dark enough sky to justify the expense of a new observatory.

Although city lights have received most of the attention, there are other sources of artificial illumination that could affect astronomical observations. These include reflections from the proposed Solar Power Satellite system and airglow from large-scale Ionospheric and Magnetospheric modification experiments. Before proceeding with such projects, it is appropriate to consider what effects they may have on astronomical observations.

Astronomical measurements can be affected either by light scattered into the line of sight or by light emitted along the line of sight. Examples of the former are moonlight, zodiacal light or city lights; sources of emission include airglow, aurorae, faint stars, and galaxies. From the various natural sources, the typical brightness of the night sky (B_s) is, in astronomical terms, equivalent to 290 10th visual magnitude (m_v) stars per square degree.[1] This is equivalent to a sky "surface brightness" of 2.09×10^{-8} stilb near 5500 Å (Allen, 1973), where 1 stilb = 1 lumen/cm^2/ster. At 5500 Å, 1 lumen = 1.47×10^{-3} Watt (W). Thus, the sky brightness B_s = 0.03 nW/cm^2/ster or, in aeronomical terms, approximately 1 kilorayleigh, since 1R (10^6 photons emitted in all directions

[1] Allen, C.W., *Astrophysical Quantities*, The Athlone Press, University of London, 1973.

per cm^2 vertical column per second) equals $0.1581/\lambda(\mathring{A})$ $nW/cm^2/ster$. In terms of its spectrum, the night sky is a combination of continuous radiation and emission lines being mostly airglow, but including (increasingly) lines of mercury and sodium reflected from streetlights.

The importance of the background sky brightness also depends on the nature of the observation being made. The astronomer's ability to study the faintest objects in the night sky (quasars, distant galaxies, faint stars and clusters in our own galaxy) is limited almost entirely by the background sky brightness and the steadiness of the atmosphere ("seeing"). In such observations, a doubling of the sky brightness requires almost a doubling of the observing time to make the same measurement. In such areas as stellar astrophysics (high resolution spectroscopy, many variable star measurements) or astrometry (stellar positions and motions) observations are generally less sensitive to the brightness of the sky. In the case of I.R. Astronomy, the thermal emission of the atmosphere itself (as well as the telescope) overwhelms all other possible sources of interference. Since astronomical measurements in the ultraviolet region are made from instruments carried above the Earth's atmosphere, artificial light sources contribute to sky brightness only if located beyond the altitude of the UV satellite or rocketborne probe.

The importance of the sky brightness to various fields of astronomy is shown in Table G-1. Table G-1 is necessarily qualitative and perhaps oversimplifies the sub-disciplines of astronomy, but it does show how various increases in the sky brightness will affect the various fields.

Table G-1
Effects of an Increase in Sky Brightness

Field	10%	100%	10 Times	100 Times
Extragalactic Astronomy	Noticeable	Serious	Prohibitive	Prohibitive
Galactic Astronomy	Noticeable	Serious	Prohibitive	Prohibitive
Stellar Astrophysics	None	None	Noticeable	Serious
Astrometry	None	None	Noticeable	Serious
I.R. Astronomy	None	None	None	None

Table G-1 presumes that any increase in sky brightness has a continuous spectrum; if the emission is instead in a few spectral lines, spectroscopic studies will be less seriously affected within each category, although broad band observations (such as photography) will be seriously affected. When considering line emissions, however, two additional points should be noted. First, the night sky emissions could coincide in wavelength with astrophysically important spectral lines. For example, the sodium emission in airglow and in streetlights obscures the important sodium absorption in galaxies, and the emission lines in atmospheric barium release experiments could interfere with a group of interesting red giant stars which show barium in their spectra. The second problem arises from the concern that if the emission lines were sufficiently intense, some of the modern sensitive detectors could be overwhelmed. For example, 1000 kR emission would obliterate the spectrum of a faint quasar on a vidicon camera.

Typical numbers to be expected in a barium release experiment are, for example, 4554Å emissions in the 1 to 30 nW/cm^2/ster range.[2] If these values are compared with the typical night sky brightness of 0.03 nW/cm^2/ster enhancement factors of 30 to 1000 times B_s may occur. For comparison, the sky brightness near 5000 Å resulting from a full moon is approximately 20 times the moonless sky brightness (B_s). As shown in Table G-2, a 20-fold increase in B_s has a dramatic effect on astronomical observation. For that very reason, telescopes at most observatories are routinely scheduled for such "dark runs" or "bright runs".

The duration of emission from a barium cloud depends on many geophysical factors, and thus each proposed modification experiment would have to be evaluated separately for its potential impact to astronomy. Fitzgerald et al. (1978) have shown that electron column densities near 10^{10} to $10^{11}/cm^2$ produce radiance levels of 0.1 to 2.0 nW/cm^2/ster–factors of 3 to 60 times higher than the night sky brightness. Such levels of "light pollution"–if frequent, long-lived, or large-scale in in scope, would have a serious impact on optical astronomy.

A possible mitigating approach might be to conduct such chemical release experiments near the time of full moon. The effects of the moonlight on observations of the artificially created emissions could be reduced greatly by isolating the emission lines with interference filters.

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[2]Fitzgerald, T.J., T.E. Eastman, J.J. Childers, L.A. Rauber, D.J. Simons, and J.H. Wolcott, "Operation Stress: Analysis of Image Intensified Photographic Data," EG&G Technical Report 1183-5100, Los Alamos, New Mexico 87544, September 1978.

Table G-2
Brightness Comparison (Approximate)

Brightness in *Kilo-Rayleighs	Wavelength Å	Source
> 5000/Å	visible range	Day sky continuum (scatter)
20000	12700 (band)	O_2 day airglow
< 6400	6708 (line)	Li release: < 2 minutes, viewed along orbit path horizontally from orbit altitude
4500	28000 (band)	OH day airglow
1100	3914, 5577, etc.	Aurora: brief brilliant stage
< 1000	4554, 4607, etc.	Ba release: < 10 sec., initial spot
300	7619 (band)	O_2 day airglow
100	visible range	Moonlit clouds
100	3914, 5577, etc.	Aurora: typical fairly bright
< 100	4554 (line)	Ba^+ from release: in selected viewing directions
< 100	4607 (line)	Sr from "doped" release: < 60 sec.
< 100	6708 (line)	Li release: < 4 minutes

*1 kR = 10^9 photons/cm^2 sec·column

Source: GSFC.

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15. Supplementary Notes

16. Abstract

NASA has initiated a program to develop and operate a Chemical Release Module Facility as part of the Solar Terrestrial Spacelab Program. This program is to function as a multi-user facility to perform chemical release experiments selected from proposals submitted by Principal Investigators in response to NASA's "Announcement of Opportunity." The Chemical Release Module (CRM) is an expendable, free-flying spacecraft which is deployed from the Space Shuttle with an attached "kick motor" which is subsequently fired to place the CRM into the orbit required. This report documents studies and contains two parts: (1) the report of a review panel, and (2) a reprinting of the environmental analysis. The task of the review panel was twofold: (a) to bring forth any new environmental considerations, and (b) to review a draft version of the report. The review panel supported the conclusion that "no deleterious environmental effects of widespread or long-lasting nature are anticipated from chemical releases in the upper atmosphere of the type indicated for the CRM program."

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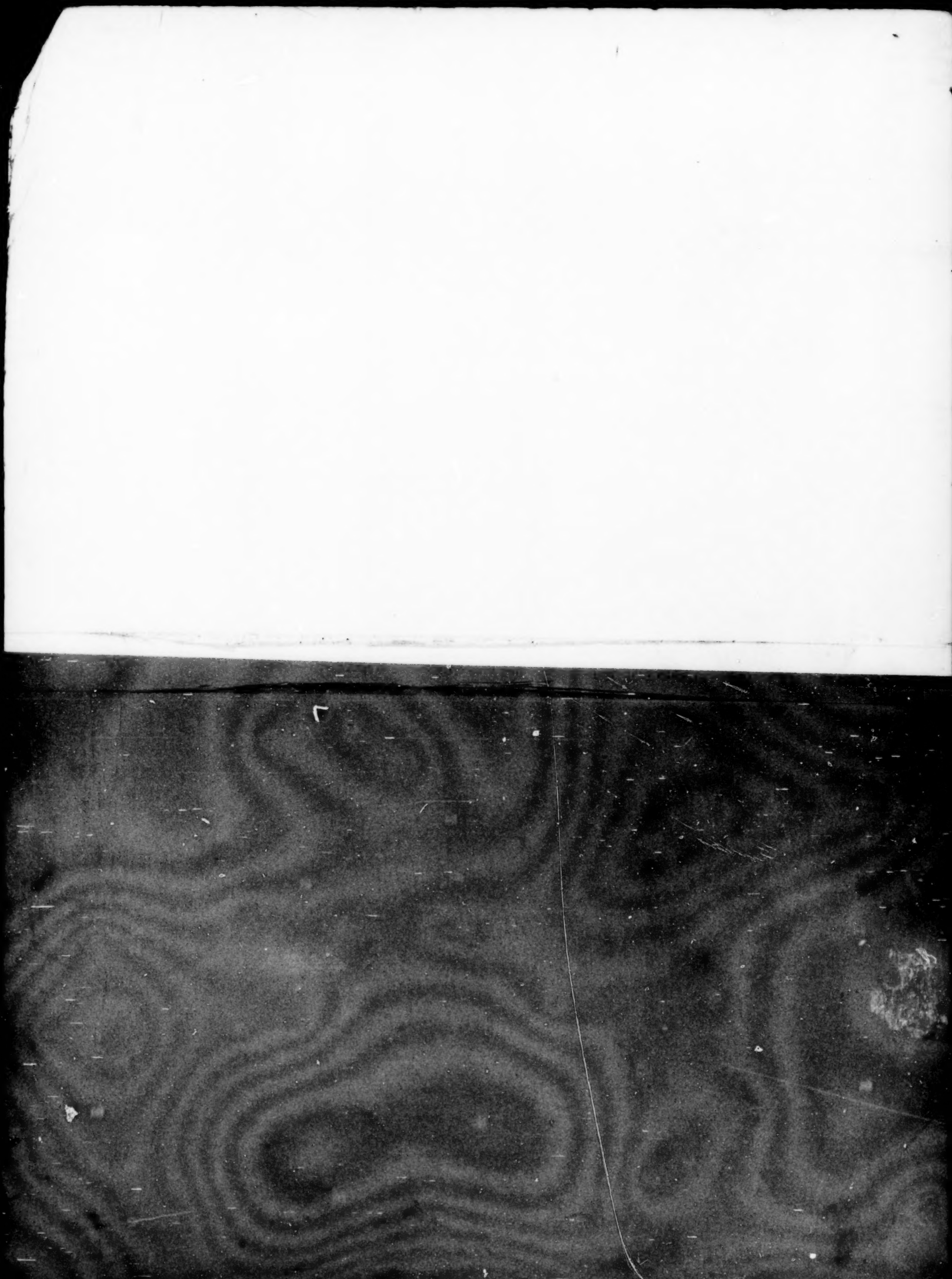

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